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The lower Cretaceous Kootenai formation in Granite and Powell counties Montana

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The University of Montana

THE LOWER CRETACEOUS KOOTENAI FORMATION IN GRANITE AND POWELL COUNTIES, MONTANA

by

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THE LOWER CRETACEOUS KOOTENAI FORMATION IN GRANITE AND POWELL COUNTIES, MONTANA.

Robert H. McGuire Jr.

ABSTRACT

The lower Cretaceous Kootenai formation exposed in Granite and Powell counties, Montana was measured and described in detail. The Kootenai formation contains several sandstone units, as well as maroon and red shales and siltstones, which often contain abundant calcareous nodules. The lowest unit is a quartz and chert pebble conglomerate or quartzitic sandstone and the top unit is the widely distributed "gastropod limestone". The Kootenai formation here contains lithologies similar to lithologies of the formation in the Sweetgrass arch, Great Falls, and southwest Montana areas. The Kootenai-Colorado "transition unit" consists of alternating dark shales and quartzitic sandstones, averaging about 150 feet in thickness. This unit is tentatively correlated with the "Blackleaf Sandy member" of the Sweetgrass arch and central Montana. A two member division on the basis of lithology is proposed to replace the three member division presently in use for this area. The lower member A is composed primarily of coarse clastics with some interbedded shale and siltstone. The upper member B includes all remaining lithologies to the top of the formation, marked by the "gastropod limestone". Fresh water gastropods, pelecypods, and ostracods show the

continental aspect of the Kootenai formation. Conglomerate-filled channels and lensing of the sandstone units, as well as certain mineralogical associations also suggest a continental environment. The Kootenai sandstones contain both primary materials and constituents derived from older sediments. The most likely source area is to the west in the Nevadian orogenic belt. The Kootenai lithologies are typical of post-orogenic terrestrial facies.

INTRODUCTION

Purpose of the Study

The lower Cretaceous Kootenai formation has been of interest to many Rocky Mountain geologists because of its importance in central Montana as an oil producer. Very little work has been done on the Kootenai formation in central western Montana and consequently detailed sections are unavailable. The primary purpose of this study is to measure and describe the Kootenai formation outcropping in Powell and Granite counties, central-western Montana.

A second purpose involves comparison and correlation of the Kootenai formation of western Montana with the formation in adjacent areas. Thirdly, the author proposes a division of the Kootenai formation into two members rather than the three member division presently used in the study area. A fourth purpose is a discussion of the Kootenai formation limits and the relationships with bounding formations.

Location of Study Area

Outcrops of the Kootenai formation are exposed along the north side of the Clark Fork River from Bear Creek to Avon and the south side of the Clark Fork River along the flanks of the Flint Creek Range, in Powell and Granite counties. (see

Figure 1, page 3). The area covers about 600 square miles from 46°36' to 46°45' North Latitude, and 112°30' to 113°30' West Longitude. The Kootenai formation is not, however, present everywhere. From these outcrops five sections were selected and studied. The sections are located and designated as follows:

Section A - Sec. 8, T. 11 N., R. 13 W.[1]; 87% exposed in a small gully between Rattler and Mulkey gulches.

Section B - Sec. 4, T. 10 N., R. 10 W.[1]; 70% exposed about one-half mile west of Hoover Creek.

Section C - Secs. 3 and 10, T. 10 N., R. 10 W.[1]; 80% exposed along Brock Creek from one-fourth mile above the Montana Phosphate Products Company Anderson Mine to about one-half mile below the mine.

Section D - Sec. 19, T. 10 N., R. 9 W.[1]; 18% exposed along the west side of Warm Springs Creek from the Anaconda Company phosphate prospect to the waterfall, one-half mile downstream.

Section E - Secs. 24 and 25, T. 9 N., R. 13 W.[1]; 56% exposed along Douglas Creek, southeast of Hall.

These sections were chosen from the somewhat limited outcrops of the Kootenai formation because of the exposure, lack of structural complication and spacing of the sections. The area is structurally disturbed and sections free from faulting are difficult to locate. Typically the formation has low resistance to erosion and exposures generally are poor. In portions of the Flint Creek Range, particularly near Mount Princeton (between Gird and Boulder Creeks), the Kootenai formation is greatly metamorphosed. A heavy forest cover makes

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[1]Montana Principal Meridian.

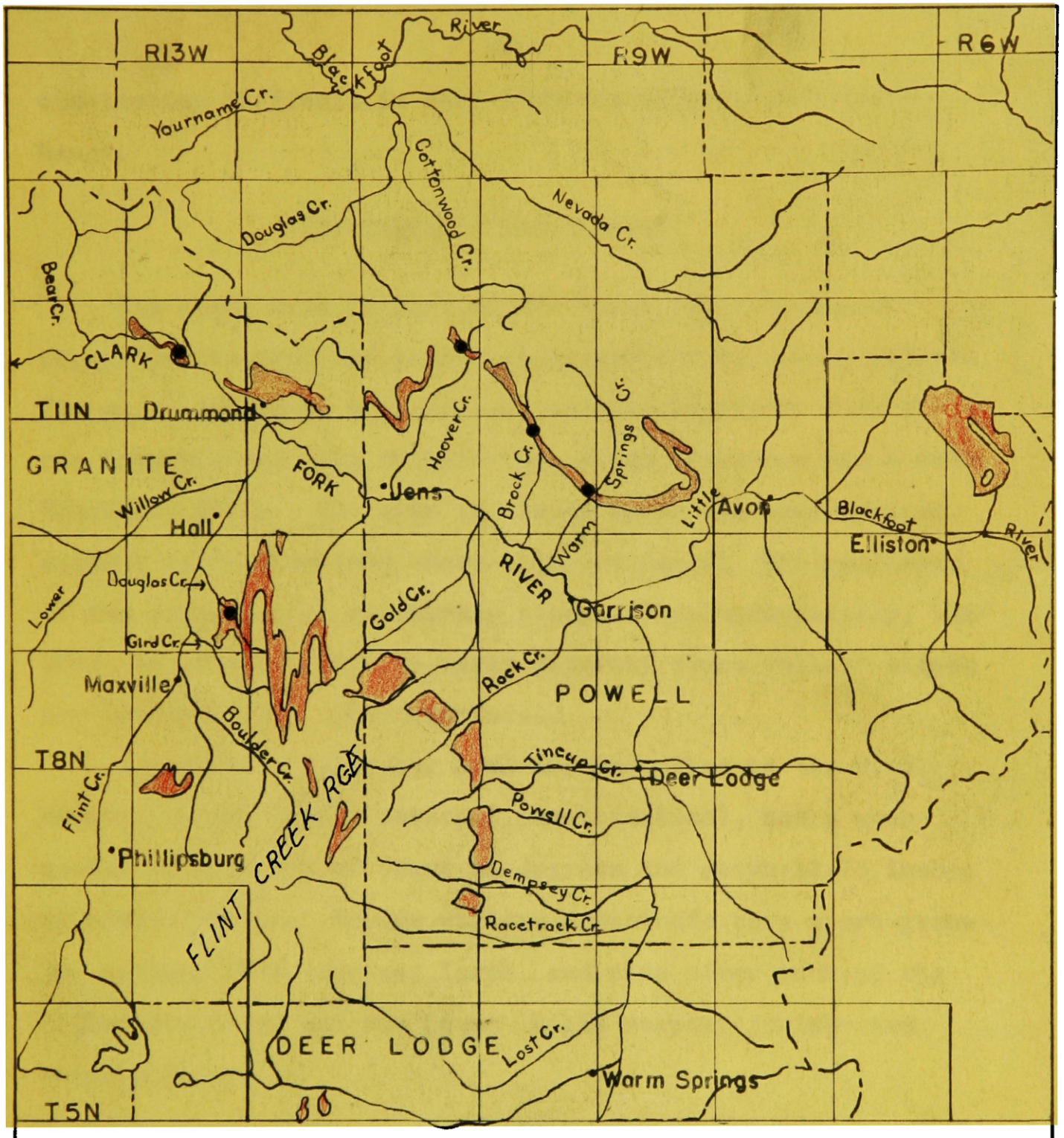


FIGURE 1 Showing Location of Kootenai Outcrops in Powell, Granite, and Deer Lodge Counties, Montana

County Line

Kootenai Outcrop

Measured Surface Section

N

0 6 12 18 Miles

examination difficult in many portions of the Flint Creek Range.

Physiography and Climate

The study area is part of the North Rocky Mountains physiographic province and is characterized by strong relief. The major drainages are the westward-flowing Clark Fork of the Columbia and its tributaries, Flint Creek and the Little Blackfoot River. The area is dissected by the many smaller streams which flow into these main drainages. The gradients of the streams are relatively steep. Physiographically, the area is in late youth or early maturity since valley slopes are dominant over upland surfaces.

The climate is rather cool and according to the U. S. Weather Bureau (1957, personal communication), has a mean annual temperature of about 44 degrees and about 12.75 inches of precipitation. Severe winters contribute to a short growing season. Fir, spruce, larch, and pine cover much of the higher elevation and the lower hills support juniper and range grasses.

Summary of Previous Work

J. W. Dawson (1885, p. 2), working in British Columbia described sandstone, shale, conglomerate and coal beds containing a Jurassic-Cretaceous flora. He named these beds the

Kootenie group after an Indian tribe which roamed this portion of the Rocky Mountains. G. M. Dawson (1885, pp. 126B-134B) found a lower Cretaceous flora, older than Dakota, in the Bow Valley region of southern British Columbia. He followed J. W. Dawson in naming the beds containing this flora the Kootenie series. Thus southern British Columbia is the type area of the Kootenie group or series.

Eldridge (1886, p. 742) mentioned Cretaceous coal-bearing rocks from the Great Falls area and assigned them to the Dakota group because of associated sandstones and because they were overlain by known Colorado group beds. Fossil plant species identical to those described by J. W. Dawson from the Kootenie group were identified by J. S. Newberry (1891, p. 192) from the vicinity of Great Falls, Montana. W. H. Weed (1892, p. 309) applied the name Kootenie to rocks of the Great Falls area containing coal, overlying the Jurassic. He arbitrarily assigned an impure limestone carrying gastropod shells to the top of the Kootenie formation. Iddings and Weed (1893) described the Dakota sandstone exposed in south-central Montana as: units composed of conglomerate and sandstone near the base which are overlain by reddish conglomerate and capped by a thin bed of fossiliferous limestone and quartzite. Their description resembles typical Kootenai lithology. Weed (1899) apparently discarded the term Kootenie for lower Cretaceous rocks of the Great Falls area and called those rocks "Cascade

formation". His "Cascade formation" included all rocks up to the top of the main producing coal seam and he assigned the overlying 300 feet of sandstone and shale capped by a fossiliferous limestone to the Dakota formation. Weed (1900) gave a lower Cretaceous age to the Cascade formation and included the overlying Dakota with the Yellowstone formation.

C. H. Fisher (1908, pp. 77-78) designated the coal-bearing rocks near Belt, Montana as the Kootenai formation and considered it equivalent, in part, to the Kootenie series of Canada. Fisher (1909, pp. 30-31) discarded the terms Cascade formation and Dakota formation for these rocks, applied the name Kootenai formation, and reaffirmed the lower Cretaceous age of the rocks.

Earl Douglass (1909) mentioned the Kootenai in his brief reconniassance of southwest Montana geology. Calkins and Emmons (1913, 1915) gave a generalized lithologic description of the Kootenai formation exposed in the Phillipsburg quadrangle of central-western Montana. They refer (1915, p. 9) to an upper gastropod limestone, occuring near Phillipsburg as well as near Yellowstone Park. J. T. Pardee (1916) briefly mentioned the Kootenai formation of central-western Montana and included beds above the "gastropod limestone" as part of the Kootenai formation. Gardner, Hendricks, Hadley, and Rogers (1946) measured and described Paleozoic and Mesozoic sections, including the Kootenai formation, from several places in central, south-central and southeastern Montana.

Condit (1918) described two Kootenai sections from southwest Montana although he included the Morrison formation with the Kootenai formation. He refers (p. 104) to the Kootenai as ".....a motley aggregation of beds.....". F. S. Honkala (1949, pp. 57-59) described a Kootenai section from the Centennial region of southwest Montana.

The Jurassic-lower Cretaceous sequence in British Columbia is presently known as the Kootenay formation, is overlain by the Blairmore, and has no Cretaceous equivalent in Alberta or Montana, according to Fox (1953, pp. 77-78). In a recent paper, W. A. Cobban (1955, pp. 107-119) described the Kootenai formation and other Cretaceous rocks of northwest Montana. He included generalized lithologic descriptions, definitions of the formation boundaries, and a discussion of the contained fossils. Wilmarth (1938, p. 1119) lists Kootenai as the approved spelling of the formation name. The evolution of lower Cretaceous Formation names is shown on Chart I, page 8.

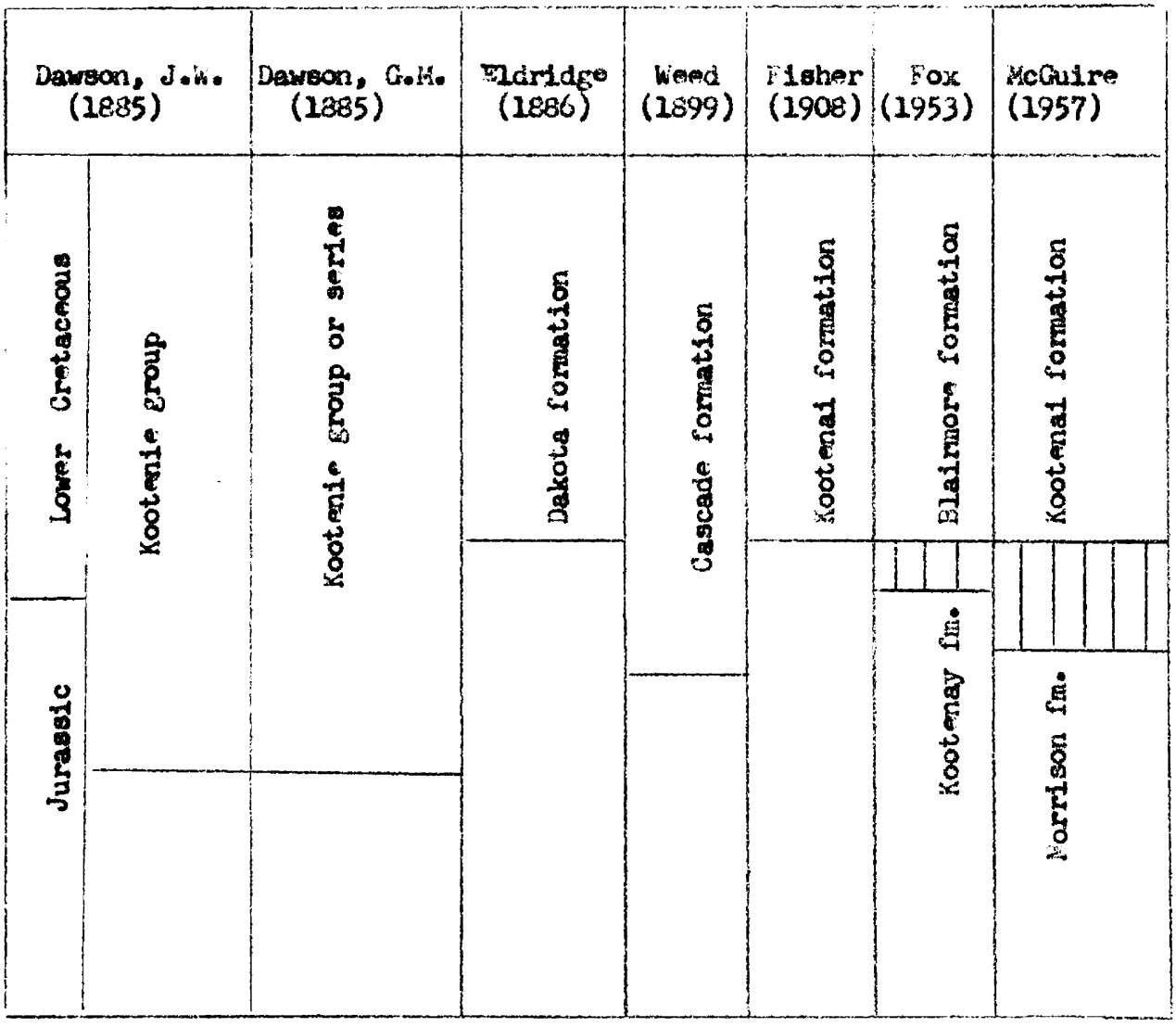
Acknowledgements

The author is indebted to Professors R. W. Fields, J. P. Wehrenberg, R. M. Weidman, and R. Yalkovsky for their suggestions and criticisms of this paper. He is especially indebted to Prof. F. S. Honkala for his patience and generosity of time for comments and criticisms. The author wishes to thank Mr. C. F. Bebber who performed the heavy mineral separations on the sandstone samples.

Chart I

Showing Evolution of Lower

Cretaceous Formation Names



STRATIGRAPHY

Local Aspect of the Formation

The term Kootenai is used as a formation name in parts of Montana for rocks of Lower Cretaceous age. Generally the lowest unit is a hard, resistant, quartzitic sandstone or conglomerate and the top is a resistant, highly fossiliferous limestone. The dominant rocks are maroon, red, green, and gray siltstones, shales, and sandstones. In the five measured sections, thicknesses vary from about 1000 to 2000 feet.

The relation of the Kootenai formation to other formations is shown in the geologic column (figure 2, page 10). /Calkins and Emmons (1915), Hanson (1952), Honkala, McLauglin, Johnson, and Bell (1956)/. In western Montana, the Morrison formation (Honkala, McLaughlin, Johnson and Bell, 1956) underlies the Kootenai formation which, in turn, is overlain by Colorado group rocks. The Morrison formation is well exposed along the flank of a small anticline in Sec. 8, T. 11 N., R. 13 W. at the base of Section A. The Morrison formation is composed here of thin sandstone and siltstone units interbedded with thicker brown, gray, and maroon fissile shales.

The Colorado group, as described by McLaughlin and Johnson (1955, pp. 120-123), totals 3640 feet in thickness at Hoover Creek in Powell County. The lower units of the Colorado group represent a transition from the Kootenai formation

Era	Period	Thick.	Formation	Lithology (ies)
Cenozoic	Tertiary		————	lava flows, intrusives, sediments
Mesozoic	Cretaceous	3750 ±	Montana group	sandstone, shale, conglomerate
		3650 ±	Colorado group	shale, sandstone
		1000-2000±	Kootenai	shale, sandstone, siltstone
	Jurassic	150 ±	Morrison	sandstone, variegated shale
		550 ±	Ellis group	sandstone, shale, conglomerate
Paleozoic	Permian	0-85	Phosphoria	phosphate rock, chert, quartzite
	Pennsylvanian	300 ±	Quadrant	quartzite
		300 ±	Amsden	siltstone
	Missis-sippian	1000 ±	Mission Canyon	limestone
			Lodgepole	limestone
	Dev.	1000 ±	Jefferson	limestone, dolomite
	Dev. (?)	380	Maywood	limestone, shale
	Cambrian	335	Red Lion	limestone
		1450	Hasmark	limestone
		365	Silver Hill	shale
		115	Flathead	quartzite
Proterozoic	Algonkian	20,000±	Belt Series	quartzite, argillite, limestone
Archean			Not exposed	

Figure 2 - Generalized Geologic Column of Formations in Central-Western Montana

to the lower Colorado black shales. No evidence of unconformity was found between the Kootenai and Colorado beds. A conglomerate at the base of the Kootenai formation may indicate an erosional disconformity. Neither truncation of the Morrison formation nor any undulatory surface was observed at the contact, and the attitude of the formations is the same above and below the contact.

Age and Regional Correlation of the Kootenai Formation

Age of the Kootenai Formation

G. M. Dawson (1885), Newberry (1891), Fontaine (1893) and Fisher (1908) considered the Kootenai formation to be lower Cretaceous in age. Throughout most of Montana it rests upon the Jurassic Morrison formation. The Kootenay formation (see Chart I, page 8) in British Columbia contains ferns, conifers, and cycads with Jurassic affinities. C. A. Fisher (1908, p. 79) quoted Sir William Dawson:[1]

> "the Kootenai series should probably be placed .....as a representative of the Urgonian or Necomian. .....It would seem to correspond in the character of its fossil plants with the oldest Cretaceous floras recognized in Europe and Asia, and with that of the Krone formation in Greenland, as described by Heer."

This, of course, refers to the lower Cretaceous rocks in Alberta and British Columbia. J. S. Newberry (1891, p. 192) assigned coal-bearing rocks near Great Falls, Montana to the

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[1] Reference not cited.

lower Cretaceous because of the similarity of fossil plant species with species from the Kootenie series of Canada. W. M. Fontaine (1893) also noted the similarity between the flora of the Kootenai (his "Great Falls group") formation of Montana and that of the Kootenie series of British Columbia. Fisher (1908), working in the Great Falls area, assigned all sediments between the Jurassic Morrison formation and the upper Cretaceous Colorado group to the Kootenai formation.

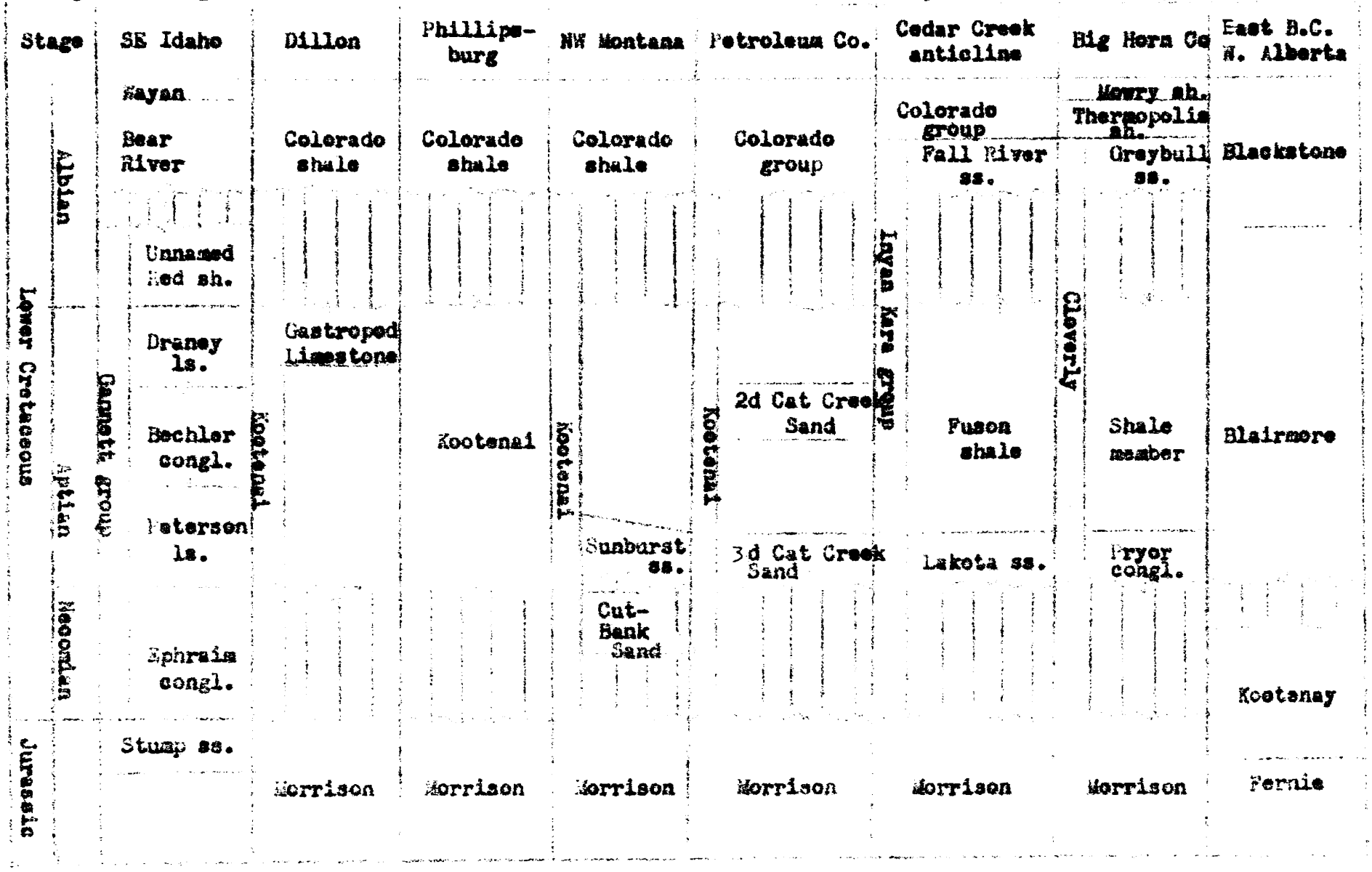
In the area studied for this report, no diagnostic fossils were found so it is necessary to rely on stratigraphic position and lithologic similarity to establish the age of the Kootenai formation. The age relationships of the Kootenai formation can best be shown by the correlation chart (figure 3, page 13). [Cobban and Reeside (1952), Fox (1953)].

Regional Correlation of the Kootenai Formation.

The correlations which follow are based on similarity of lithology and stratigraphic position only.

The Kootenai formation averages about 1300 feet in Powell and Granite Counties (see County index map, figure 4, page 14) thickening to the southwest and north, and thinning to the east. The lower Cretaceous rocks of western Alberta have a total thickness of several thousand feet. The Kootenai formation sections from Judith Basin, in central Montana, average about 550 feet (Fisher 1908, p. 83), thinning towards the southeast.

Figure 3 - Age and Correlation of Lower Cretaceous Formations in Mont., SE Idaho, Alberta, B.C.



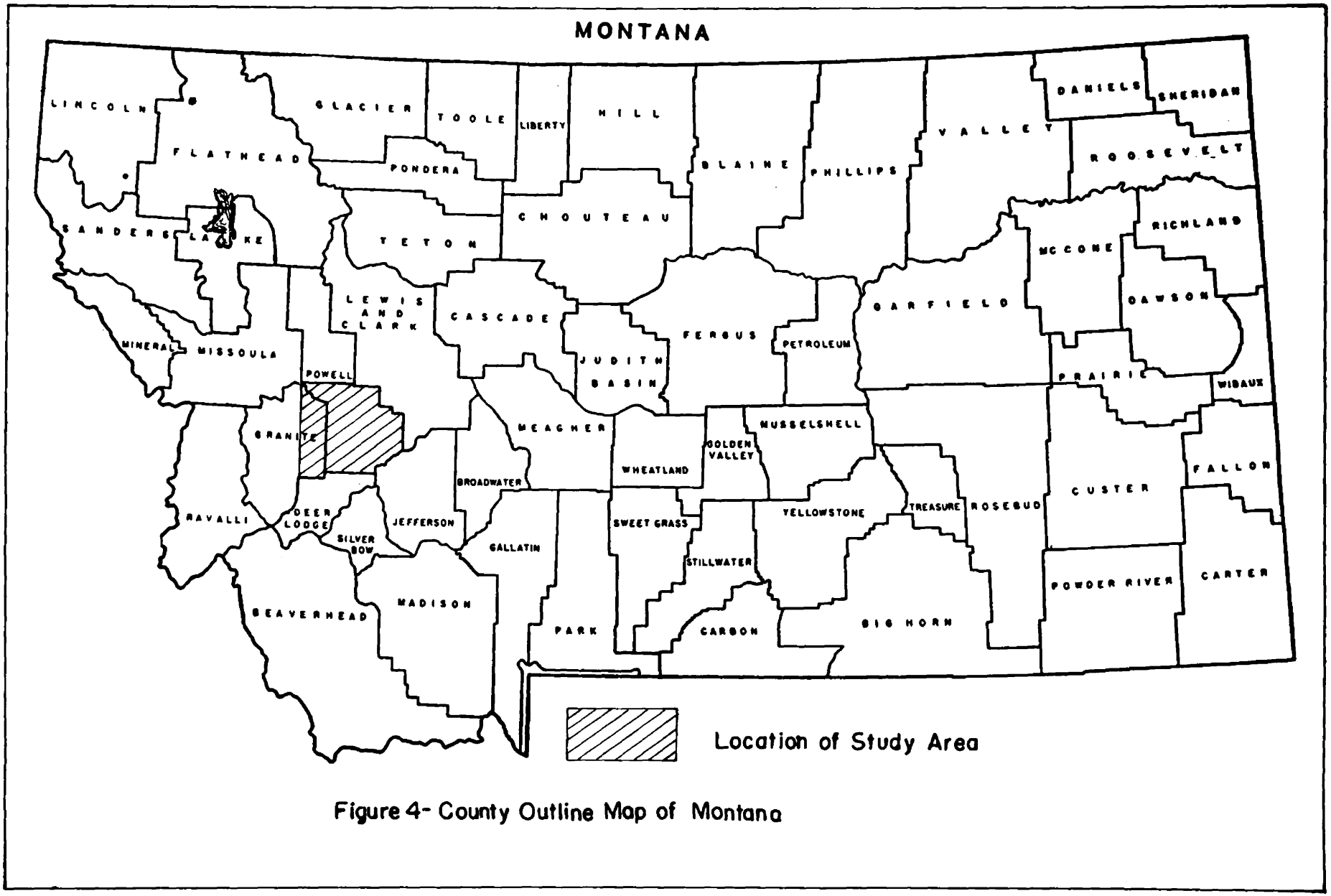


Figure 4- County Outline Map of Montana

In Carbon county the Kootenai formation equivalent, the Cloverly formation, is only 100 feet thick (Gardner, et al, 1946). The Kootenai formation averages 1000 feet in the Sweetgrass arch of Toole, Liberty, and Pondera counties (Cobban, 1955, p. 107). Sections from Jefferson, Meagher, Fergus, Madison, and Stillwater counties are intermediate in thickness. In southeast Idaho (Cobban and Reeside, 1952) the lower Cretaceous is represented by the Gannett group with three formations, Peterson limestone, Bechler conglomerate, and Draney limestone equivalent to the Kootenai formation. These three formations have a total thickness of 3500 feet (Moritz, 1953, p. 63).

Throughout most of Montana, the Kootenai formation rests unconformably upon the Jurassic Morrison formation. The basal conglomerate or sandstone is almost always present, known variously as: "the Cut Bank sandstone" in the Sweetgrass arch of northern Montana, "the Third Cat Creek Sand" in the Cat Creek field of Petroleum County, "the Lakota Sandstone" from the Cedar Creek anticline of Dawson and Fallon counties, "the Pryor conglomerate member" in Big Horn County, "the lower Blairmore conglomerate", in British Columbia. In the Garrison-Phillipsburg area, the conglomerate, as such, is not always present, locally grading into a quartzitic sandstone.

Red, green, or maroon shales are typical lithologies in

the area studied as well as in the Sweetgrass arch and central Montana. Most sections contain significant amounts of coarser clastics and in Big Horn County (Gardner, et al, 1946, p. 85) the entire section is sandstone and conglomerate.

The "gastropod limestone" occurs in the Centennial region of southwest Montana (Honkala, 1949, p. 58), in Jefferson County (Gardner, et al, p. 14) and in Yellowstone Park (Calkins and Emmons, 1915, p. 9). Near Belt, Montana, a fossiliferous limestone is found near the top of the Kootenai formation (Fisher 1908, p. 80). A dark shale with gastropods and pelecypods may mark the top of the formation in northwest Montana (Cobban, 1955, p. 108). The top of the formation is a shale or sandstone.

Kootenai and Kootenai-equivalent rocks are, in Montana, overlain by Colorado group sediments. In southeast Idaho, upper Cretaceous sedimentation is represented by part of the Wayan formation (Moritz, 1953, p. 65).

Field and Laboratory Methods

After examination of the several outcrop areas of the Kootenai formation in the study area, five sections were selected which were considered to be best exposed and structurally least disturbed. The three methods of measurement used were: (1) The Brunton compass and steel tape method. This was the most common method of measurement, used mainly where the ground surface was fairly regular. From the measured

outcrop distances, the true thickness was computed trigonometrically. (2) The Brunton compass method described by Lahee (1941, pp. 425-426) was used mainly where the ground surface was uneven. The strike and dip of the beds were checked at short intervals. (3) Plane table and alidade measurement was used only once, as a time saving device, to measure a covered interval. None of these methods is completely accurate but probably the measurement with Brunton and tape, used most commonly, is most nearly accurate.

In Section A, continuous samples were taken for each significant lithologic change but in the remaining sections, only single samples were taken from each lithology. This change was made because the time involved in continuous sampling and the necessary trenching was not commensurate to results obtained. Section A is measured in greater detail because an effort was made to describe each lithologic change. Beds of varying lithology were noted and described in sections B, C, D, and E but, if thin, they were not individually measured nor sampled. Field descriptions included: tentative rock name, texture, structure, exposure, erosional resistance. The samples are stored in the Geology Department, Montana State University, Missoula.

The author has made use of a qualitative method for recording the erosional resistance of each unit of the formation. The basal conglomerate or conglomeratic sandstone exposed

at Section A was arbitrarily assigned a resistance of 10. The resistance of other units was estimated as a fraction of this value. This relative resistance was plotted for each unit on the columnar sections of Plate I.

The samples were studied in the laboratory using a binocular microscope. A Wentworth (Wentworth, 1922) grade sample card was used to compare and estimate rock sample grain sizes. The mineralogical composition was estimated without cutting thin sections and the percentage of each component was also estimated.

Five sandstone samples, one from the lower part of each section, were selected for study and a bromoform heavy mineral separation was performed on each sample. The samples were disaggregated and the light and heavy fractions separated. Disaggregation proved very difficult because the sandstones were cemented with silica and low in porosity. They were heated, immersed in water, reheated, and finally were crushed in a mortar. The grains fractured in this process and only grains showing either roundness or euhedral outline can be considered as being unchanged. The heating may have destroyed some mineral species and complete disaggregation was impossible. Fifty grams of each sample were used for the separation. The results were not, nor were expected to be, quantitative.

Lithologic Descriptions

Detailed descriptions of Sections B, C, D, and E will be found in the Appendix to this paper. Section A, measured in Section 8, T. 11 N., R. 13W., about five miles west of Drummond, contains the following lithologies:

Unit	Thick. (ft.)	Cum. Thick. to Top of Unit	Description
206	14.5	2017	Limestone, medium crystalline, in beds 2 in. to 2 ft. thick, averaging about 1 ft., black to dark gray. Rock contains many gastropod and pelecypod fossils (up to 60% or so of the volume of the rock in some places); rock has petroliferous odor, is very hard and resistant, forming a prominent topographic rib.
205	1.5	2002.5	Siltstone, sandy, slighty calcareous, massive, dark brownish-gray, weathers lighter brownish-gray, very resistant.
204	3.5	2001	Shale, silty, calcareous, moderately fissile, breaks down into 1/2 in. blocky fragments, red brown on fresh surface, weathering light reddish-gray.
203	5	1997.5	Limestone, sandy, in beds 1-6 in. thick, very hard and brittle, medium brownish gray. Fine-grained sand and silt particles comprise an estimated 40% or more of the rock.
202	26.5	1992.5	Shale, very fissile, very calcareous, mottled maroon and light brown, with interbedded shaly limestone. Unit contains 4 beds about 6 in. thick of argillaceous limestone, massive, fine crystalline, medium brownish-gray.

201	32.5	1966	Sandstone, fine-grained, clayey, silty, very calcareous, in beds 3 in. to 3 ft. thick, medium brownish-gray. Unit contains 14 beds of sandstone separated by shale, calcareous, fissile, in beds 2 in. to 2 ft. thick, brownish-maroon.
200	28	1933.5	Shale, soft, fissile, highly calcareous, mottled light brown, maroon, dark maroon, and reddish-maroon, containing calcareous maroon-weathering nodules in beds 1-2 in. thick as well as scattered. (NOTE: The shales throughout the upper 200 ft. of this section have been considerably deformed so the thicknesses listed in this section are only approximate.)
199	1.5	1905.5	Sandstone, like unit 198, probably part of the same unit.
198	9	1904	Sandstone, medium-grained, calcareous, massive. Composition: quartz grains, clear and frosted, 60%, unidentified dark grains 10%, matrix of clay-silt and carbonate cement 30%. Color, medium to light gray with reddish-maroon-weathering patches about 1 in. in dia., which may be more calcareous and weather more rapidly, leaving pits. (A small fault, which strikes parallel to the strike of the beds, has a displacement which reduces the thickness of this unit by several feet.
197	5.5	1895	Siltstone, clayey, very calcareous, in beds 1/4-1/2 in. mottled maroon and light brown.
196	9.5	1889.5	Shale, soft, fissile, very calcareous, with a 10 in. bed of calcareous siltstone, mottled maroon and light brown at 1886 ft. Shale is also mottled maroon and brown and contains some 1 in. dia. nodules of the same color in the upper 1 ft.

195	11.5	1880	Shale and siltstone, shaly, both calcareous, both maroon, in alternating beds 1-2 in. thick. Both contain many maroon-weathering nodules, scattered and in beds; a bed of mottled maroon and white weathering siltstone at 1872-1874 ft.
194	14.5	1868.5	Shale, very soft and fissile, strongly calcareous, bright reddish-maroon, mottled maroon and brown.
193	2.5	1854	Sandstone, fine-grained, silty, very calcareous, massive, medium brownish-gray, slightly porous. Sand-size grains compose about 50%; clay and silt size particles with carbonate cement about 50%.
192b	13.5	1851.5	Shales, very calcareous, some silty, all very fissile, all soft and highly weathered, in beds 6 in.-1 ft. thick. Colors are: maroon, gray, mottled maroon and gray, and black.
192a	4	1838	Limestone, alternating in beds 1-3 in. thick with shale, fissile, soft, very calcareous, weathering light gray. Limestones of lower 2 ft. are dark gray; those of upper 2 ft. are medium gray-brown, weathering lighter gray-brown; both limestones are silty.
191	3.5	1834	Shale, fissile, silty lower 1 ft., very calcareous, dark gray, weathering light gray.
190	13.5	1830.5	Sandstone, fine-grained, silty, very calcareous, medium gray, nonporous; alternating in 6 in. - 1 ft. beds with shale, soft, fissile, very calcareous, reddish brown.
189	5.5	1817	Shale, very fissile, calcareous, light brownish gray, with a bed of silty limestone, medium gray,

			weathering light brown; nodules scattered throughout the shale.
188	2	1811.5	Shale, very fissile, highly calcareous, light maroon-brown.
187	1	1809.5	Limestone, argillaceous, shaly, in beds 1/8-1/4 in. thick, medium brownish-gray fresh surface, weathers light reddish-brown.
	10	1808.5	Covered, shale, maroon-gray and sandstone, gray.
186	6.5	1798.5	Limestone, sandy, in beds 1/4-1/2 in. thick, medium gray, weathers light brown. The fine-grained sand particles compose an estimated 30% of the rock. Also present is 2-3% of biotite. The limestone is in 6-12 in. beds interbedded with 1-4 in. beds of shale, calcareous, soft and fissile, dark gray.
185	3	1792	Siltstone, sandy, calcareous, in beds less than 1 mm thick, medium brownish-gray. Siltstones show ripple or current marks and are interbedded with shale, soft, calcareous, fissile, in beds 2-3 in. thick, dark gray; a 6 in. bed of limestone, fossiliferous, brownish-black, weathering light gray at 1792 ft.
	3	1789	Covered, maroon shale.
184	4	1786	Siltstone, lower 1 ft. is sandy, very calcareous, light brown, low porosity. Quartz and biotite compose about 20% of this 1 ft. interval. The upper 6 in. is a limestone, containing many gastropod fragments, dark gray to black, weathering light gray. Between these are alternating nodular limestones, dense, argillaceous, dark gray, weathering light brownish-gray, and shale, fissile, calcareous, maroon.

183	4	1782	Shale, soft, very fissile, thin-bedded, strongly calcareous, bright maroon, contains seams of calcite.
	25.5	1778	Covered, probably shale-sandstone.
182	13.5	1752.5	Sandstone, fine-grained, calcareous, silty, in beds 1/4-1 in. thick, bright maroon and light brownish-gray. Composition: quartz 20-40%, feldspar 20%, unidentified dark minerals 10%, silt-clay matrix and carbonate cement 30-40%. In the maroon portions of the bed, the grains are coated with iron oxide on weathered surfaces but are light gray-brown on fresh surfaces.
181	10.5	1739	Shale, silty and micaceous (biotite) in the lower 3 ft., fissile, strongly calcareous, medium grayish-maroon, contains scattered gray, maroon-weathering, calcareous nodules 1-2 in. average dia.
180	4.5	1728.5	Sandstone, fine and medium-grained, calcareous, massive, very hard and brittle, medium gray fresh and weathered. Composition: quartz 65%, unidentified dark minerals 30%, carbonate cement. Estimated porosity is 5% or less.
179	3	1726	Siltstone, clayey, slightly or non-calcareous, in beds 1/4-1/2 in. thick, breaks into 1/2 in. blocks, dark maroonish-gray.
178	17	1723	Sandstone, fine-grained, calcareous, with basal foot of unit strongly calcareous, bedding averages 1/2 in., light brown fresh and weathered. Composition: quartz 50%, feldspar 15-20%, unidentified dark minerals 20%, biotite 1-2%; the rest is a clayey and silty matrix with calcareous cement.

177	25.5	1706	Shale, and shale, silty, interbedded; shale is fissile, slightly calcareous, bright maroon, containing a 3 in. bed of nodules, calcareous, at 1694 ft.
176	26.5	1680	Sandstone, medium and fine-grained, in beds about 1/4 in. thick, locally calcareous, locally shaly (upper 8 in. is mostly shale interbedded with sandstone), light brown fresh and weathered. Composition: quartz 5-15%, feldspar 10-30%, unidentified minerals 10-15%, phlogopite 5-20%, biotite 5-10%, clay matrix and calcareous cement about 25%.
175	23.5	1654	Sandstone, shaly, interbedded in beds less than 1 ft. thick with shale. The sandstone is fine-grained, moderately calcareous, in beds 1/4 in. thick, medium gray. Composition: quartz 40%, dark grains (chert?) 15%, biotite 2-3%, unidentified matrix and carbonate cement 45%. Shale is soft, fissile, moderately calcareous, bright reddish-maroon, contains red-weathering nodules averaging 1 in. dia.
174	2	1630.5	Sandstone, like unit 171.
173	10.5	1628.5	Shale, sandy in the basal 2 ft., silty from 1619-1622 ft., fissile above 1622 ft.
172	12.5	1618	Sandstone, like unit 171 except locally finer-grained and not so calcareous.
	12	1605.5	Covered, probably maroon shale or siltstone.
171	4	1593.5	Sandstone, medium-grained, very calcareous, massive, very hard and brittle, medium gray. Composition: quartz 70%, unidentified dark minerals 10%, and carbonate cement 20%; porosity low.

			Grains are mostly angular and subangular. The rock has many calcite-filled fractures.
	17.5	1589.5	Covered, probably like Unit 170.
170	19.5	1572	Shale, interbedded in 2-3 in. beds with shale, silty; about 50% of each lithology. Both are fissile and splintery, slightly calcareous to non-calcareous, brownish-maroon.
169	3.5	1552.5	Sandstone, medium-grained lower 6 in., becoming fine-grained to silty at the top, calcareous, platy in beds 1/4 in. thick, gray-brown, porosity about 15%. Composition: quartz 20-50%, unidentified dark minerals 15%, biotite 15%, silt-clay matrix and carbonate cement 20-45%.
168	6.5	1549	Sandstone, medium to coarse-grained, very calcareous, in beds 1/8-1/4 in. thick, very soft and friable, light brownish-gray. Composition: quartz, 75%, black chert and/or magnetite 15%, biotite 2-3%; remainder is mostly carbonate cement. Grains are angular to subrounded, well sorted, both clear and frosted.
	3	1542.5	Covered.
167	11.5	1539.5	Sandstone, medium-grained, calcareous, in beds 1/4-3 in. thick, medium brownish-gray, weathers light brown, estimated porosity 10-20%. Composition: quartz 75%, dark chert 10%, feldspar 5%. The remainder is unidentified matrix and carbonate cement. The grains are mostly subangular with quartz grains both clear and frosted. Several

			3-6 in. beds of shale, silty, maroon, thin-bedded, slightly calcareous. Unit is about 75% sandstone and 25% shale.
166	19.5	1528	Shale, and siltstone, shaly. The shale is slightly calcareous, soft, slightly fissile, brownish maroon. Three 1 ft. beds of shaly siltstone occur in the upper 10 ft. of unit. Siltstone is slightly calcareous to non-calcareous, in beds 1/4 in. thick, medium maroonish-brown.
	25	1408.5	Covered, probably shale like unit 165.
165	14.5	1483.5	Shale, soft, fissile, calcareous, brownish-maroon.
164	35.5	1469	Shale, varies from shale, soft, fissile, non-calcareous, red-brown, to shale, sandy, fine-grained, calcareous, medium gray-brown. Bedding averages 6 in. to 18 in. Unit is more calcareous towards the top. Sandy shale is moderately porous.
163	2	1433.5	Shale, silty, very fissile, non-calcareous, dark reddish-brown, contains some calcareous nodules.
162	1	1431.5	Sandstone, fine and medium-grained, clayey, slightly calcareous, medium brownish-gray, estimated porosity 5%-10%. Composition: quartz 40-50%, feldspar 20%, biotite and muscovite 2%, remainder is a matrix of clay and silt.
161	1	1431.5	Shale, hard, fissile, slightly calcareous, maroon.

160	4	1429.5	Sandstone, fine-grained, silty, lower 1 ft. strongly calcareous, in beds 1/4 in. thick, medium gray-brown. Composition: quartz and feldspar 50%, minor biotite, rest is silt and clay matrix with calcareous cement.
159	3	1425.5	Shale, locally silty, hard, very fissile, non-calcareous, medium maroonish-brown.
158	1	1422.5	Limestone, shaly, silty, bedded 1/4 in. thick, medium reddish-brown, weathers light reddish-brown.
157	1	1421.5	Limestone, silty, dense, in beds 1/4-1 in. thick, medium brownish-gray, weathering light reddish-brown. Rock contains an estimated 30% of silt sized particles.
	1	1420.5	Covered, shale.
156	1.5	1419.5	Mudstone, calcareous, in beds 1/4-1/2 in. thick, medium brownish gray, weathering light reddish-brown. Composition: sand-size particles (mainly quartz) 40%, silt-clay matrix and carbonate cement 60%, very resistant.
155	4	1418	Shale, very fissile, non-calcareous lower part becomes strongly calcareous upper part, medium to dark brown.
154	3.5	1414	Claystone, silty, moderately calcareous, in beds 1/4-2 in. thick, medium brownish-gray, weathers light reddish-brown.
153	8	1410.5	Shale, very soft and fissile, non-calcareous lower part, strongly calcareous upper part, brownish-maroon.
	20.5	1402.5	Covered, probably maroon shale.

152	12.5	1382	Sandstone, like unit 151 except calcareous, in alternating 6 in. - 1 ft. beds with shale, fissile, non-calcareous, dark reddish-brown. Unit is about 2/3 sandstone, 1/3 shale.
151	4.5	1369.5	Sandstone, clayey, medium-grained, slightly calcareous, in beds 1/4-1/2 in. thick, medium to light gray-brown, moderately porous. Composition: quartz grains 30-40%, chert (?) 20%, feldspar 25%, minor phlogopite and biotite in a matrix of clay and silt. Grains are mostly subrounded.
150	7	1365	Shale, silty, micaceous, slighty fissile, non-calcareous to slightly calcareous, thin-bedded.
149	2	1358	Shale, soft, fissile, non-calcareous, medium brownish-maroon.
148	5.5	1356	Claystone, silty, micaceous, slightly calcareous, in 1/4 in. beds, bright maroon.
147	12.5	1350.5	Shale, like unit 146 except somewhat harder. The lower 1 ft. contains some 1-3 in. dia. calcareous nodules.
146	15.5	1338	Shale, soft, very fissile, slightly or non-calcareous, bright maroon.
145	2.5	1322.5	Sandstone, fine-grained, shaly, micaceous, fairly calcareous, in 1/8-1/4 in. beds, light brownish-gray. The lower 6 in. has some stringers and veinlets of calcite. Composition: quartz 30%, kaolinized feldspar 30%, phlogopite (?) 5%, fine-grained matrix and carbonate cement 35%.
144	66	1320	Covered, probably shale, containing calcareous nodules, siltstone, and some fine-grained gray sandstone.

143	3.5	1254	Shale, fissile, silty some places, micaceous, very calcareous, thin-bedded, dark dull maroon fresh, weathers to slightly lighter reddish-maroon.
142	24.5	1250.5	Siltstone, shaly, slightly calcareous, reddish maroon, some calcareous nodules of the same color scattered throughout.
141	17.5	1226	Siltstone, sandy, and shale, silty, alternating in beds 1-3 in. thick. Siltstone is pinkish-gray to maroon. Fine-grained quartz sand composes about 25-30%. Siltstone is in 1/4-1/2 in. beds and is quite calcareous. Shale is fissile, slightly calcareous to non-calcareous, bright maroon.
140	6	1208.5	Sandstone, subgraywacke, fine-grained, highly calcareous, platy, in 1/8-1/4 in. beds, cross-bedded, light gray-brown. Composition: quartz, frosted and clear, subangular-subrounded 30%, feldspar (decomposed) 15%, biotite 2-5%, unidentifiable matrix and carbonate cement 50%, including 15% black chert.
139	8	1202.5	Claystone, silty, very slightly fissile, slightly calcareous, few nodules at 1190 ft., grayish maroon. Nodules are 3-6 in. dia., color medium gray, weather to same color as claystone.
138	28	1194.5	Shale, fissile, non-calcareous, medium reddish-brown, many scattered calcareous nodules, same color as shale.
137	32.5	1166.5	Shale, silty in places, less fissile than unit 136, medium brownish-maroon. About 5-10% of this unit is composed of nodules in beds or scattered, calcareous, maroon, hard.

136	39	1134	Shale, brownish maroon, soft, fissile, silty 1102-1104 ft., calcareous nodules, same color, scattered throughout the unit.
135	20	1095	Sandstone, fine-grained, shaly in some places, in beds 1/4-1/2 in. thick, platy, slightly calcareous, color medium brown, porosity low. Composition: quartz, unidentified dark grains, biotite, about 70%, clay and silt matrix with some carbonate cement 30%.
	3	1075	Covered.
134	1.5	1072	Shale, silty, micaceous, fissile, non-calcareous, dark chocolate brown.
133	4	1070.5	Sandstone, silty, fine-grained, massive, non-calcareous, medium brown, weathers light brown. Composition: quartz grains, feldspar, biotite, about 60%, silt and clay 40%.
132	5.5	1066.5	Shale, micaceous, soft, fissile, non-calcareous, medium brown, grades into units 131-133.
131	11	1061	Siltstone, sandy, shaly, non-calcareous, bedding 1/8-1/4 in. thick, medium brownish-gray. Fine sand-sized grains of dark quarts, frosted quartz and biotite make up 30-40% of the rock. There is a bed of calcareous nodules 3-10 in. dia. at 1060 ft.
	14.5	1050	Covered, probably siltstone-shale like units 129-130.
130	3.5	1035.5	Shale, hard, fissile, slightly calcareous, medium grayish-brown.
129	4	1032	Siltstone, shaly, calcareous the lower 1.5 ft., in beds about 1/4 in. thick, medium grayish maroon.

			These shale-siltstones units have transitional contacts but nevertheless are quite distinct.
128	23	1028	Shale, moderately fissile, although fissility varies considerably, slightly or non-calcareous, bright brownish maroon. About 15% of the unit is maroon-weathering, calcareous nodules 2 in. dia. The bedding appears to bend around the nodules which are much more resistant than the shale.
127	4.5	1005	Siltstone, micaceous, shaly, variably calcareous, bedding 1/4 in. thick, medium brownish-maroon; contains many calcareous nodules scattered and in beds up to 3 in. thick.
126	32	1000.5	Shale, soft, fissile, non-calcareous to slightly calcareous, medium brownish-maroon, silty from 987-989 ft. Between 989-990 ft., scattered calcareous nodules 2-4 in. dia. of the same color.
125	20.5	968.5	Shale, and interbedded sandstone, shaly, in beds 1-1.5 ft. thick. Shale is micaceous, silty in places, moderately fissile, slightly calcareous, dark reddish brown. Sandstone is fine-grained, calcareous, in beds 1/8-1/4 in. thick, medium brownish-gray. Composition difficult to determine but seems similar to units 122 and 124. The sand-sized particles make up an estimated 60% of the rock.
124	10.5	948	Sandstone, arkosic, medium and fine-grained, slightly calcareous, mostly massively bedded but thin-bedded in some places. Color medium brownish-gray, porosity probably 5% or less. Composition: quartz grains, frosted and subangular 50%, feldspar 30%, unidentified dark grains 10%, unidentified matrix and carbonate cement 10%.

123	9.5	937.5	Shale, soft, very fissile, non-calcareous, dull dark brown.
122	3.5	928	Sandstone, medium-grained, calcareous, massive, medium gray, not very porous (probably 5% or less), fractures have calcite fillings. Composition: quartz 70%, feldspar 10%, unidentified dark grains 10%, minor biotite, fine-grained matrix and carbonate cement 10%. The sand is moderately well sorted and with grains mostly sub-angular.
121	3	924.5	Siltstone, shaly, sandy, non-calcareous, in beds 1/8-1/4 in. thick. Sand grains (10%) are fine-grained quartz and biotite. Color is medium maroonish-brown.
120	11	920.5	Sandstone, medium and fine-grained, slightly calcareous, medium gray, moderately porous. Composition: quartz 40-60%, biotite 5%, black chert 10%, unidentified matrix 10-30%. The grain size decreases gradually towards the top of the unit. The sandstone is massive in the basal 3 ft., platy, in beds 1/4-1/2 in. thick in the upper 8 ft., moderately hard.
119	2.5	909.5	Shale, fissile, soft, non-calcareous, bright maroon, non-resistant, very abrupt change from 119 to unit 120.
118	11.5	907	Shale, silty, fissile, locally calcareous, maroon; interbedded in 1 ft. beds with sandstone, like unit 117 except calcareous. At 905 ft., there is a bed of calcareous nodules which are 1 ft. dia., and weather olive drab.
117	9	895.5	Sandstone, fine-grained, slightly calcareous, in beds 1/8-1/4 in. thick, platy, slightly porous, steel gray.

			Composition: quartz, feldspar (?), biotite, with matrix of silt and clay. Alternating with siltstone, locally shaly, non-calcareous, gray-maroon. The two types of lithology are interbedded in lenses 1-3 in. maximum thickness giving a wavy appearance to the exposure from 890-893 ft. Unit is about 1/3 siltstone and 2/3 sandstone.
116	19	886.5	Shale, fissile, soft, locally calcareous, bright brownish-maroon, grades into unit 117.
115	4	867.5	Shale, silty in lower part, fissile, varies from non-calcareous to slightly calcareous; dull, dark, brownish-maroon.
	5.5	863.5	Covered, probably soft, maroon, shale like unit 115.
114	1.5	858	Sandstone, sub-graywacke, fine-grained, non-calcareous, weathered so that bedding is obscured, maroon and tan, low porosity. Composition: quartz about 30%, dark chert 20%, biotite and muscovite (?) 5%, unidentifiable matrix 45%. This is interbedded with olive drab claystone, hard and non-calcareous.
113	4.5	856.5	Shale, fissile, very slightly calcareous, splits into 1/8-1/4 in. plates, dark olive drab.
112	6	852	Sandstone, like unit 111, interbedded in 6 in. to 1 ft. beds with shale, slightly fissile, non-calcareous, dull dark-maroon. The change from one lithology to another is very abrupt. This unit is about 2/3 sandstone and 1/3 shale.
111	6.5	846	Sandstone, sub-graywacke, fine and medium-grained, calcareous, platy, in 1/2 in. beds, cross-bedded, salt and pepper gray.

			Estimated composition: quartz 50%, biotite 5%, chert 15%, feldspar 10%, matrix of clay and silt 20%. This sandstone is moderately well indurated and quite porous.
110	3.5	839.5	Siltstone, shaly, non-calcareous, very soft, up to 10% sand in some layers, including some biotite grains, dark brownish-gray on fresh surface, weathers maroon.
109	1.5	836	Shale, soft, very fissile and splintery, non-calcareous, medium maroon.
108	7	834.5	Shale, sandy, silty, slightly calcareous, dull maroon. Fine-grained, sand-size grains compose 5-30% of the rock, silt-size 10-30%; remainder is clay-size. Sand grains are quartz and dark biotite. A thin bed of calcareous nodules, 2 to 4 in., occurs at 833 ft.
107	4	827.5	Shale, soft, fissile, non-calcareous, bright maroon.
106	9	823.5	Shale, silty soft, fissile, micaceous, calcareous, medium dull maroon. Silt-size particles make up 10-40% of the rock.
105	2.5	814.5	Shale, silty, micaceous, soft, fissile, calcareous, medium dull maroon.
104	11	812	Shale, sandy, silty, micaceous, calcareous, beddding 1/4 in. thick, medium brownish-gray. Fine-grained sand-size particles make up 0-50%, silt and clay size 50-100%. Sand grains are mainly quartz (frosted and clear) and biotite.
103	4	801	Siltstone, shaly, slightly calcareous, bedding 1/4 in. thick, platy, medium grayish-maroon.

102	16.5	797	Siltstone and shale, in 6 in. - 1 ft. alternating beds, non-calcareous. The siltstone is in 1/4 in. beds and is gray and maroon; shale is moderately fissile, maroon. The upper 4 in. is shale only.
101	4	780.5	Shale, silty, slightly fissile, calcareous, micaceous, very thin-bedded, dark maroon-gray.
100	4	776.5	Sandstone, silty, shaly, slightly calcareous, cross-bedded, fine-grained, platy, bedding 1/8-1/4 in. thick. Grains are quartz, dark mica, and feldspar, about 40%. Silt and clay compose the rest.
99	2	772.5	Shale, fissile, sandy, very slightly calcareous, dark grayish-maroon, resistant.
98	12.5	770.5	Covered, shale, soft, fissile, maroon.
98	30	758	Shale, silty, micaceous, fissile, non-calcareous, maroon. About 10-15% of the interval is bright maroon-weathering, calcareous nodules, 1-3 in. dia., scattered and bedded.
97	8	728	Siltstone, shaly, slightly fissile, non-calcareous, micaceous, dull maroon, with a 4 in. bed of silty, nodular limestone at 722 ft.
96	12	720	Shale, fissile, slightly calcareous, bright maroon, with thin beds of nodular limestone at 709 ft., 717 ft., and 719 ft. Nodules are maroon-weathering, average 4-6 in. dia.
95	7.5	708	Siltstone, shaly, micaceous, non-calcareous, platy, bedding 1/4-1/2 in. thick, dull, dark maroon. There are occasional calcareous nodules of the same

			material which average about 3-4 in. dia.
94	4.5	700.5	Shale, silty, soft, fissile, calcareous, dull maroon.
93	1.5	696	Siltstone, sandy, slightly calcareous, soft, bedding 1/8-1/2 in. thick, platy, maroon-gray. Composition: quartz, feldspar and biotite, about 30%, in a matrix of clay and silt particles with carbonate cement.
92	4.5	694.5	Sandstone, very calcareous, bedding more massive than in units 90-91; otherwise the color and composition are very similar.
90-91	9	690.5	Sandstone, graywacke, medium-grained, platy, in beds 1/4-3/8 in. thick, cross-bedded, poorly indurated yet resistant, very slightly calcareous, gray. Composition: quartz, subrounded, frosted, 60%, black chert 15%, biotite, muscovite (?) and pinkish feldspar 20%, unidentified cement 5%. The contact between 89 and 90 is rolling, showing as much as 1 ft. of relief. This is probably due to squeezing rather than representing an erosional disconformity.
89	12.5	681.5	Siltstone, clayey, and sandstone, silty. The siltstone is compact, bedding 1/8-1/4 in. thick, slightly calcareous. The sandstone is fine-grained, composed of grains of limestone, quartz and feldspar. The matrix is silt and clay-size material and the cement is carbonate. Rock is highly weathered and mineral identification is difficult. The sand occurs as lenses within the siltstone. Also, a 2 x 16 in. limestone lens occurs at 683 ft.

88	4.5	669	Shale, silty, slightly fissile, quite calcareous, micaceous, dull gray-maroon.
87	5	664.5	Siltstone, shaly, very slightly calcareous, slightly fissile, bedding mostly 1/4-1/2 in. thick, dark grayish-maroon.
86	8	659.5	Shale, fissile, soft and splintery, slightly calcareous, medium brownish-maroon.
	11.5	659.5	Covered, probably shale with interbedded thin beds of limestone.
85	38	640	Shale, soft, fissile, splintery, calcareous, grayish-maroon. Several beds of differing lithology are noted as follows: a. 602-602.5 Shale, very soft, slightly fissile, non-calcareous, thin-bedded, light greenish-brown. b. 602.5-603 Shale, same as (a) only more fissile and splintery. c. 617.5-618 Siltstone, non-calcareous, dark brownish-maroon. d. 627.5-628 Limestone, nodular, argillaceous, dense, dark gray, weathering light blue-gray. Contains a number of fragments of gastropod and pelecypod shells.
84	7	602	Limestone, shaly, calcareous, with interbedded shale. The shaly limestone is mostly medium to dark gray-brown, weathering light gray or buff. The shale is hard, fissile, dark gray to black, weathering lighter gray . The lower 18 in. is a conglomerate composed of 20%

			2-6 mm pebbles, subangular and subrounded of black and light brown claystone and argillaceous limestone. The matrix (80%) also seems to be grains of the same material cemented with carbonate. Limestone and shale are in alternating beds.
83	5	595	Claystone, slightly to strongly calcareous, massive, hard and brittle, medium brownish-gray, weathering buff and light gray.
82	1.5	590	Shale, silty, hard, slightly fissile, slightly calcareous, medium gray-brown.
81	3.5	588.5	Limestone, argillaceous, dense, lower 2 ft. massive, dense, dark green, weathering buff; overlain by a zone of fractured limestone recemented with aragonite or calcite, pseudomorph after aragonite. Upper 1 ft. is same color but is medium crystalline. The top 6 in. is composed of dense, medium gray, 3-4 mm pebbles of limestone cemented by darker carbonate.
80	5	585	Limestone, shaly, medium gray-brown, weathering buff. The limestone has, at least locally, 5-10% muscovite or phlogopite. Bedding is 1/8-1/2 in. thick. The lower 6 in. has much less carbonate and a high percentage of fine sand and silt-size grains. In this interval, about 5% of the rock is composed of subangular pebbles of light brown claystone, slightly calcareous.
79	5	580	Limestone, argillaceous, dense to finely crystalline, medium to dark brownish-gray, weathering tan; interbedded with limestone, shaly, very brittle, in beds 6 in. thick.

78	5.5	575	Limestone, shaly, slightly fissile, bedded 1/4-1 in. thick, medium gray, weathering light gray. Some dark gray to black, rounded to subrounded, particles are 2-9 mm dia. in one 6 in. bed, which might be clay galls.
77	13	569.5	Shale, soft, very calcareous, fissile, thin-bedded, dark gray, weathering lighter gray.
76	2	556.5	Limestone, argillaceous, dense, medium gray-brown, weathers tan. The lower 1 ft. is massive but the upper 1 ft. has bedding 1/8-1/4 in. thick and resembles travertine; rock is very brittle.
75	2	554.5	Shale, soft, fissile, with interbedded shale, silty, bedding 1/16-1/4 in. thick, calcareous, red to gray fresh, weathering light gray-brown.
74	1	552.5	Sandstone, fine-grained, silty, clayey, locally calcareous, medium brownish-gray, weathers light brownish-gray. Sample is highly weathered and poorly exposed.
73	3.5	551.5	Shale, soft, fissile, very calcareous, dark gray, weathering light gray.
72	1.5	548	Siltstone, shaly, calcareous, bedded 1/4-1/2 in., medium gray-brown, weathers light brown, contains many casts, molds, and fragments of pelecypods, gastropods.
71	2	546.5	Shale and sandstone, interbedded in beds 2-6 in. thick. Sandstone is fine-grained, non-calcareous, composed mainly of rounded to subrounded frosted quartz grains, cemented with silica. Shale is silty, fissile, calcareous, medium gray. The upper 6 in. has a few

			2-3 in. dia. medium gray-light-gray-weathering nodules of limestone, argillaceous, fine to medium grained, crystalline. The lower 3 in. has 20-30% of rounded black chert pebbles 2-6 mm in dia.
70	1	544.5	Siltstone, clayey, siliceous, dark gray on fresh and weathered surfaces, very resistant.
69	.5	543.5	Shale, hard and fissile, non-calcareous, medium gray.
68	2	543	Claystone, silty, very slightly calcareous, bedded 1/4-1 in., dull, dark grayish-maroon, non-porous, grades gradually into unit 59, ripple marked.
67	1.5	541	Limestone, argillaceous, breaks with conchoidal fracture, dense except for middle 4 in. which are fine to medium crystalline. Color is light brownish-gray, weathering light tan.
66	4.5	539.5	Shale, silty, calcareous, medium gray, weathers lighter gray, contains some nodules of argillaceous limestone, 2-3 in. dia. Nodules weather light buff and are mostly dense but some coarsely crystalline.
65	1	535	Shale, hard and resistant, slightly fissile, slightly calcareous, in beds 1/8-1/4 in. thick, dark, dull maroon and gray.
64	1.5	534	Siltstone, very hard, slightly calcareous, mottled gray and gray-green. Lower 1 ft. contains stringers of calcite. Upper 6 in. divided by a thin shaly bed.
63	1	532.5	Shale, soft, fissile, slightly calcareous, dark brownish-gray on fresh and weathered surfaces.

62	4	531.5	Claystone, silty, non-calcareous, non-porous, very hard and brittle, mottled dull maroon and dark gray, fresh and weathered surfaces. Massive except slightly shale in upper 6 in.
61	1	527.5	Shale, soft, fissile, very slightly calcareous, dark gray fresh and weathered.
60	3	526.5	Limestone, argillaceous, dark gray, weathers buff and light gray. The lower 1.5 ft. is nodular in appearance with shale seams surrounding brittle, hard nodules 2-8 in. dia. The upper 1.5 ft. is shale.
59	2.5	523.5	Shale, very soft, moderately fissile, slightly calcareous, dark gray.
58	5	521	Shale, silty, soft, slightly fissile, non-calcareous, medium gray on fresh and weathered surfaces.
57	4.5	516	Shale, soft, fissile, slightly calcareous, mottled maroon and gray. Contains a few silt-sized particles and a few flakes of muscovite.
56	2	511.5	Limestone, dense, argillaceous, thin-bedded and platy, becoming more shaly at top, dark gray.
55	9.5	509.5	Limestone, argillaceous, dense, massive, with alternating beds of limestone, shaly, in 1/8-1/4 in. beds, medium gray in color and weather buff. About 50% of each lithology.
54	1	500	Shale, slightly fissile, calcareous, thin-bedded, dark gray weathers light gray. Contains about 20% of silt and fine sand-size grains of calcite.
53	2	499	Limestone, argillaceous, dense, dark gray, weathers buff; has

			interbedded fine-grained sandstone and claystone as the center 6 in. The sandstone is composed of grains of claystone and the 6 in. layer is only slightly calcareous.
52	1	497	Shale, soft, fissile, dark gray, weathers same color; contains many small fractures filled with calcite giving a striped appearance.
51	.5	496	Limestone, shaly, dense, dark gray, weathers buff, very resistant.
50	2	495.5	Shale, brittle, fairly fissile, variably calcareous, dark gray, weathers light gray.
49	32	493.5	Limestone, argillaceous, massive in 2-5 ft. beds, dark gray, weathers buff and light blue-gray; interbedded with shale, slightly fissile, calcareous, light gray fresh, weathering buff, in beds 1-2 ft. thick.
	52	461.5	Covered, represents lithology like units 46-7-8.
48	18	409.5	Claystone, calcareous, medium gray brown, weathers buff; interbedded with shale, dark gray, slightly fissile, calcareous, buff weathering. The lower 2 ft. is in beds 6 in. thick but the rest is massive, separated by 2-4 in. shale seams. Unit is about 1/4 shale, 3/4 claystone.
47	20	391.5	Covered, represents limestone interval, shaly, buff weathering. No sample.
46	5.5	371.5	Shale, soft, fissile, calcareous, maroon-gray; interbedded with claystone, calcareous, medium gray, weathering light gray. Unit contains about 50% of each

			lithology in beds 6 in. - 1 ft. thick.
45	21.5	366	Shale, maroon, containing small sub-rounded pebbles of argillaceous limestone from 5 mm to 2cm dia.; interbedded with claystone, calcareous, light gray, weathering light greenish-gray, also containing lighter weathering pebbles of argillaceous limestone. The shale is soft and fissile. Relative percentages of shale and claystone not determinable because of deformation of bed; estimated at 50% for each.
44	7.5	344.5	Limestone, argillaceous, dense, massive, light greenish-gray, weathers blue-gray; contains numerous sub-angular to sub-rounded pebbles of red, red-weathering cal-careous siltstone, dia. 2 mm to 5 cm. Pebbles constitute about 5% of this interval.
43	3.5	337	Claystone, calcareous, in beds 2-4 in. thick, light gray, weathering light blue-gray.
	5.5	333.5	Covered.
42	8	328	Limestone, argillaceous, dense, shaly and massive, dark gray, weathers buff, highly fractured and recemented.
41	4	320	Limestone, argillaceous, dense, dark gray, weathers buff. Highly fractured and recemented. Sandy from 316-317 ft., breaks into 2 to 6 in. slabs.
40	14	316	Limestone, argillaceous, dark gray on fresh surface, weathers light gray and buff. From 302-307 ft. it is highly fractured and recemented. 307.5-312 ft. is a bed of calcareous sandstone, fine-grained, mainly carbonate with

			a small percentage of quartz. The matrix appears to be clay and the cement is carbonate. 313-316 ft. is a series of alternating massive and shaly limestone, fossiliferous throughout. Fossils are pelecypod shell fragments, not very numerous.
39	5.5	302	Claystone, massive, except shaly lower 1 ft., calcareous, color same as unit 38.
38	3	296.5	Claystone, calcareous, fossiliferous, containing fragments of gastropods and pelecypods; massive, dark green gray fresh surface, weathers medium gray to buff. Many small stringers and veinlets of secondary calcite.
37	23.5	293.5	Limestone, argillaceous, dense, dark gray, weathers buff to light blue gray; interbedded with gray calcareous shale beds: 1.0' thick from 273-274 .5' thick from 279-279.5 .3' thick from 282-282.3 1.5' thick from 285-286.5 1.0' thick from 290-291 Limestone between the shale beds is massive and resistant. Shale is poorly exposed.
36	4.5	270	Limestone, dense to finely crystalline, argillaceous, in beds 6-12 in. thick, dark gray fresh surface, weathers buff.
35	1	265.5	Limestone, argillaceous, massive, medium gray, weathers buff, has up to 20% of detrital material, claystone and limestone grains, 1/4-1/2 mm. dia.
34	3.5	264.5	Sandstone, fine to medium-grained, very calcareous, flaggy, medium brownish-gray on both fresh and weathered surfaces. Composition:

			limestone grains 55%, claystone grains 35%, chert grains 15%, clay matrix and carbonate cement 25%.
33	4.5	261	Limestone, argillaceous, dark gray, weathers buff. Bedding massive but with one 6 in. bed of shaly limestone, same color, at 257 ft. 255.5-257 ft. is a conglomerate of sub-rounded to sub-angular pebbles and grains, 1 cm maximum dia. Pebbles and grains are mainly claystone, non-calcareous, black, weathers dark gray. The matrix is buff, argillaceous limestone. The pebbles compose about 30% of the bed. There are a few fragments of pelecypod shells.
32	3.5	256.5	Limestone, argillaceous, like unit 31 but with two beds of claystone, brittle with conchoidal fracture, gray, weathering light gray.
31	2.5	253	Limestone, argillaceous, shaly, bedding 1/8-1/4 in., medium gray-brown on fresh surface, buff weathering, one 2 in. bed limestone, dense, massive, medium gray, weathering medium gray.
30	1	250.5	Shale, fissile, calcareous, thin-bedded, tan, fresh and weathered. Grades into unit 31.
29	1.5	249.5	Claystone, calcareous, brittle, light gray, weathers light tan; Shale, calcareous, brownish gray, about half of each lithology. Only observable difference between the two is the shale, is fissile and a little darker in color.
28	2	248	Shale, fissile, slightly calcareous, medium reddish-maroon, contains a few calcareous nodules, 1-2 in. dia., light gray, light blue-gray weathering.
27	4.5	246	Limestone, argillaceous, dense

			thin bedded, medium gray to light gray fresh surface, buff to tan on weathered surfaces.
26	5.5	241.5	Limestone, dense, light gray, weathers light tan; interbedded with shale, hard, siliceous, fissile, light gray. The shale beds are 1-12 in. thick and have 1/16-1/8 in. laminations. The limestone has 6-12 in. bedding. Unit is about 1/2 limestone and 1/2 shale.
25	2	236	Limestone, argillaceous, massive, dark gray on fresh surface, weathers light blue-gray. Highly fractured and recemented with calcite.
24	4.5	234	Limestone, argillaceous, light gray, buff weathering, platy; contains several 1/2-4 in. shale seams. Shale is very calcareous; medium gray, fresh and weathered, soft and fissile with a 4 in. brownish-maroon shale seam, containing some 3-6 mm fragments of calcareous siltstone (mostly angular).
23	8.5	229.5	Siltstone, strongly calcareous, maroon; interbedded in beds 2-6 in. thick with shale, dark gray, calcareous. Unit is about 1/3 silty shale, 2/3 calcareous siltstone. Contains 2-3 in. dia. calcareous nodules, dense, light gray, buff-weathering. Shale is slightly fissile. Bedding apparently bends around the nodules.
22	19	221	Shale, silty, variably fissile, calcareous, red-maroon, containing scattered calcareous nodules, medium gray, finely crystalline, about 4 in. average dia. Shale is more calcareous around nodules.
21	14	195	Siltstone, very calcareous, bedding not distinct, medium dark maroon on fresh and weathered surface.

	8	181	Covered.
20	7	173	Shale, variably fissile, strongly calcareous, in beds 1/8-1/4 in. thick or massive, dark gray. Contains a small amount of rounded, frosted, quartz grains.
	8.5	166	Covered.
19	13.5	157.5	Shale, fissile, slightly calcareous, dark blue-gray. Contains limestone, nodular, microcrystalline, dark gray on fresh surface, weathers medium gray, 144 - 145 ft. From 145-156 ft. shale is more splintery, less calcareous. Scattered calcareous nodules 2 in. dia. throughout unit.
	7	141	Covered.
18	21	134	Shale, very fissile, strongly calcareous, maroon; interbedded in 2 ft. beds with limestone, microcrystalline, light gray, weathers buff.
17	12.5	113	Shale, fissile, calcareous, maroon, contains scattered nodules of light gray-weathering limestone, 2-12 in. dia.; interbedded with limestone, shaly, maroon, weathers light red brown, containing a few scattered veinlets and stringers of calcite. Unit is about 3/5 shale and 2/5 limestone.
16	3.5	100.5	Siltstone, non-calcareous with a few calcareous stringers, dark brownish maroon. Contains up to 10% of sand grains, 1/4-1/2 mm average dia.
15	23.5	97	Sandstone, medium-grained, quartzitic, slightly calcareous, mostly massive, locally cross-bedded, medium to light gray on

			fresh and weathered surfaces. Composition: quartz, subrounded, frosted, 60%, dark chert grains 25-30%, fine-grained matrix with siliceous and calcareous cement 5-10%; porosity low. Some fragments of ferruginous siltstone, 3-15 mm dia., subrounded to subangular. At 80 ft. there is a 10 in. bed of dark red-brown, coarse-grained sandstone (graywacke) containing 40% quartz, 40-50% dark red-brown chert. This bed also contains about 15% ferruginous silt fragments. Unit becomes slightly finer-grained in upper 5 ft. Change from unit 14-15 is very abrupt.
14	5.5	73.5	Shale, lower 2 ft. fissile, very calcareous, dark red-brown. No sand grains observed. Limestone, shaly, upper 4 ft., thin-bedded, same color on fresh surface as lower 2 ft., weathers a lighter red-brown.
13	6	68	Limestone, shaly, lower 4 ft., dark gray, weathers medium gray. Upper 2 ft. shale, dark red-brown, strongly calcareous, resembles unit 12 in color, size and amount of sand grains, has scattered calcareous nodules, like unit 12, 2-3 in. dia. Shale is somewhat more fissile than unit 12.
12	4	62	Shale, forms blocky fragments, slightly calcareous except locally strongly calcareous around nodules, dark red-brown. Contains 2-3% of rounded quartz and chert grains 1/4-1/2 mm, and scattered calcareous nodules from 3-16 in. dia., microcrystalline, medium gray, weathering medium gray. Bedding appears to bend around the nodules.
	21.5	58	Covered.

11	2.5	36.5	Sandstone, medium to coarse-grained, quartzitic, well sorted, non-calcareous, massive, light-gray fresh surface, light brown weathered. Composition: quartz grains, subrounded, sub-angular, 90%; red-brown to black chert fragments 5%, siliceous cement 5%, no matrix determinable.
10	2.5	34	Sandstone, medium-grained, quartzitic, non-calcareous, banded, dark maroon and tan. Dark fraction contains sub-rounded to rounded chert grains 30%, and quartz grains 70%, coated with hematite. The light bands contain quartz grains, frosted and sub-rounded 90%, dark chert 5%, siliceous cement 5%.
9	2.5	31.5	Siltstone, sandy, clayey, in beds 1/4 in. thick, medium gray on both fresh and weathered surfaces; Composition: quartz 10%, clay-size material 30%; remainder is silt-size grains.
8	2.5	29	Sandstone, medium and fine-grained, mottled light-brown and dark maroon with 1/2-1 in. lens-shaped splotches of light brown; dark maroon portion has 50% gray, rounded chert grains, 25% smoky quartz grains and 25% silt-size particles; cement is probably ferruginous. Some 1-2 in. shale beds, dark red-brown, containing about 5% of 1/4-1/2 mm quartz grains.
7	2.5	26.5	Sandstone, medium and coarse-grained, non-calcareous like unit 6 but with interbedded, thin , shaly siltstones, mottled light and dark brown weathered, fresh is brownish-gray. Composition: quartz grains, frosted, about 60%, chert grains about 30%

			matrix of clay and siliceous cement 10%. Sandstone composes 70% of unit, shaly siltstone 30%.
6	7.5	24	Siltstone, interbedded with sandstone. Siltstone is non-calcareous; contains about 30% of medium sand-size quartz. Sandstone is medium-grained, non-calcareous, reddish-gray. Composition: quartz, frosted and clear, 50%, chert, brown, red, or gray, 40%, silty matrix and siliceous (?) cement 10%. Unit is about 70% siltstone and 30% sandstone.
5	4	16.5	Sandstone, fine to coarse-grained, non-calcareous, tan or brown on fresh and weathered surfaces. Composition: quartz and chert, angular to subrounded, 90%, unidentified matrix and silica cement 10%.
4	3	12.5	Siltstone, sandy, non-calcareous, gray. Composition: medium-grained chert and quartz grains 15%, silt-size particles 50%, clay-size material about 35%. (NOTE: Units 1 to 4 are gradational and boundaries are drawn mainly on pebble content.
3	1.5	9.5	Sandstone, subgraywacke, conglomeratic, non-calcareous, bedding indistinct, gray. Composition: chert pebbles 5-15 mm dia., 10%, fine-grained quartz and chert grains 40%, silt-clay matrix and cement (siliceous?) 50%.
2	2	8	Conglomerate, similar to unit 1, non-calcareous, bedding indistinct. Composition: chert and quartzite pebbles 20%, silt-clay matrix and siliceous (?) cement 80%.
1	6	6	Conglomerate, quartzitic. In

top 2 ft., bedding is shown by alignment of pebbles but is indistinct lower part. Composition: pebbles of black chert and white to gray quartzite, 60%, average dia. 1-2 cm, well rounded to subangular; matrix of 1/4-1 mm chert and quartz grains with siliceous cement 40%. This unit is very resistant and supports prominent cliffs.

The following descriptions are of part of the Jurassic Morrison formation exposed below the base (unit 1) of Section A.

8	38	122	Siltstone, clayey, variably calcareous, brown, with some interbedded brown shale.
7	17	84	Siltstone, clayey, sandy in places, calcareous, light brown, contains some interbedded thin, tan, shale beds.
6	12.5	67	Shale, fissile, tan, contains two brownish maroon shale beds in the lower 2 ft.
5	6	54.5	Siltstone, slightly shaly, calcareous, light brown, in beds 1/4 in. thick.
4	8.5	48.5	Shale, fissile, variably calcareous, dark brownish gray, contains 5 to 10% of 1 in. dia. nodules, calcareous, dense, gray, weathering brown.
3	17	40	Siltstone, locally sandy, medium brown, in 2-6 in. beds with inter-bedded shale, fissile, calcareous, tan.
2	10.5	23	Shale, fissile, calcareous, tan

			in upper 8.5 ft., maroon in lower 2 ft. Tan shale contains about 20% of calcareous nodules, 1-4 in. dia., weathering tan.
1	12.5	12.5	Sandstone, fine-grained, silty, calcareous, in 1/4-6 in. beds, cross-bedded, containing 1 ft. shale bed at 6 ft., medium brown, weathering light brown, resistant.

Heavy Mineral Study

The light and heavy fractions from the bromoform separations were examined under the binocular microscope. Petrographic oil-immersion examination of the heavy fraction resulted in identification of the mineral species shown in the table below. Amphiboles and pyroxenes were not separated and are listed in Table 1 as amphibole-pyroxene. The sixth column contains the frequency symbols used for the mineral occurrences. (modified from Milner, 1940, p. 457)

Table 1

Showing mineral species and frequency of occurrence.

No. A 91

magnetite - a
apatite - c
phlogopite - c
pyroxene -
amphibole - c
andalusite - r

No. B 3

magnetite - c
specular hematite - c
phlogopite - r
fluorite - r
pyroxene -
amphibole - c
black opaque - r

No. C 43

magnetite - c
hematite - r
phlogopite - r
apatite - r
amphibole -
pyroxene - c

No. D 3

Pollution of sample; sample invalid

No. E 3

magnetite - c
apatite - c
phlogopite - r
muscovite - r
zircon - r
black opaque - r

Frequency symbols

a. . . abundant
c. . . common
r. . . rare

Interpretation of these data will be undertaken in the section on environment. (See page 61)

Subdivision of the Kootenai Formation

Throughout most of Montana a general two member division is observed: 1) a lower sequence of sandstones, shales and conglomerates and 2) an upper sequence of shales with varying amounts of sandstone and, locally, limestone. In northwest Montana, according to Cobban (1955), the Kootenai is divided into two members. The lower member is divided into three zones; in ascending order, the Cut Bank sand, the Sunburst sand, and the Moulton sand. This lower member also contains intercalcated mudstone and shale. The upper member is composed of green, red, and purple mudstones, shales, sandstones, and siltstones. The upper member lithologies contain more abundant micas and other igneous minerals than do the units of the lower member. This division is present in Powell and Granite counties. The thicknesses of these members vary as also do their percentage of the total section.

In the past, the Kootenai formation in the area of study has been divided into three members. McLaughlin and Johnson (1955, pp. 120-122) give the following divisions:

> "(a) a lower sandstone and red mudstone and shale unit, conglomeratic at the base, with nodular limestone in the mudstones and shales, and approximately 400 feet thick; (b) a middle limestone, dense, well bedded, and interbedded with dark shales, dark gray

> to black but weathering nearly white, approximately 250' thick; and (c) an upper unit of maroon and dark sandstones, siltstones, and mudstones, topped by the widely recognized 'gastropod limestone', the unit being approximately 900 feet thick."

Although this description is approximately accurate, detailed field studies indicate that the thickness of the limestone "b" member averages much less than 250 feet and that this interval contains interbedded calcareous shale equal to or greater than the limestone thickness. Furthermore, many of the light weathering limestones from several sections are actually claystones and some are non-calcareous. These claystones do present an appearance similar to that of the "b" member limestones. The "b" member is best developed near Section A west of Mulkey gulch. Along Brock Creek (Section C), the limestones appear to grade laterally into claystones and shales which occupy approximately the same stratigraphic position.

Any division must be made on the basis of lithology as no biostratigraphic zoning is possible. The most obvious separation is between the lower, coarser clastics, conglomerates and sandstones; and the upper shales, siltstones, limestones, and sandstones. A twofold breakdown rather than the former threefold division is herein proposed. All five sections show this division although the lower sandstones contain some finer clastics and the upper part contains some

coarser clastic material. The top of the lower member is placed just below the first thick shale unit above the base and is designated the A member, including the basal conglomerate and all of the lower resistant sandstones, mostly cross-bedded and quartzitic. The remaining thickness is called the B member and includes all other units through the top of the "gastropod limestone". The following table shows the units and thicknesses included in the A member of this proposed division. (see also plate I in pocket).

Table II

Section	Units	Thickness
A	1-15	97'
B	1-3	71'
C	1-13	135'
D	1-9	218'
E	1-6	147'

The author believes these divisions would provide units more easily mappable than those of the older system although the light-weathering limestones and claystones locally produce a striking pattern on aerial photographs.

The Kootenai - Colorado "Transition Unit"

Between the "gastropod limestone" and the lowest, thick, black shales of the lower Colorado group are 105-250 feet of strata which are well exposed on Brock and Warm Springs Creeks. This was referred to as a "transition unit" between the two formations by McLaughlin and Johnson (1955,

p. 122). On Brock Creek (Section C) the thickness is 165 feet, consisting in the lower 110 feet of interbedded black shales, siltstones, black argillaceous limestones, and in the upper 55 feet of ripple marked quartzite and black shales.

The unit is about 210 feet thick at Warm Springs Creek; the lower 150 feet is covered, and the upper 60 feet being well-sorted, white quartzite which strongly resembles the Pennsylvanian Quadrant quartzite as developed in the area. The covered interval contains a sequence of softer beds as shown by an abrupt flattening in the slope of the hillside. The quartzite supports a 30-foot waterfall.

At Douglas Creek, the interval is 105 feet thick with only two sandstones exposed, 2 and 15 feet thick, respectively. The "transition unit" totals 250 feet at Hoover Creek, containing interbedded calcareous sandstones and shales. The resistant quartzite of Brock and Warm Springs Creeks is not developed here. Pardee (1916, p. 212) says:

> "Next above this (the "gastropod limestone")[1] limestone and forming the topmost stratum of the Kootenai is a 100-foot bed of sandstone and shale. It is generally inconspicuous but in the Garnet Range from Brock Creek east it has been partly transformed to a quartzite that forms prominent reefs and knobs."

Although the "transition unit" apparently is present over the entire area studied, it is unequally developed. Also, the

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[1] Parentheses are the present author's.

black shales of this interval are more characteristic of lower Colorado group shales than of Kootenai formation shales. The "gastropod limestone" and basal conglomerate or conglomeratic sandstone provide two easily recognizable boundaries for the formation. The author believes this "transition unit" should be included with the Colorado group because 1) the unit has lithologic affinities with lower Colorado group sediments and, 2) the "gastropod limestone" provides a natural upper formation boundary.

Stebinger (1918, p. 158-161) named the Blackleaf sandy member from Blackleaf Creek, northwest of Great Falls. In the type locality, the Blackleaf sandy member consists of 500-700 feet of dark marine shales and gray sandstones which are the lowest units of the Colorado shale. The Blackleaf sandy member rests on the Kootenai formation and is overlain by the black Colorado shales, forming a distinct unit.

The Kootenai-Colorado "transition unit" in the study area occupies the same stratigraphic position as does the Blackleaf sandy member in the Sun River area. The lithologies of both units are similar. In Powell and Granite counties, the "transition unit" is readily distinguished from both the Kootenai formation and the black Colorado shales. Therefore the "transition unit of the study area is tentatively correlated with the Blackleaf sandy member of northwest Montana.

TECTONIC FACTORS AFFECTING DEPOSITION OF KOOTENAI FORMATION

A résumé of Jurassic and Cretaceous tectonics is necessary because of the influence of tectonic activity on sedimentation. During Jurassic time, the Cordilleran geanticline divided the Cordilleran geosyncline into an eastern and western trough. A sea covered most of the future Rocky Mountain region, withdrawing and advancing occasionally. The late Jurassic Nevadian disturbance, affecting Oregon, Washinton, and western Idaho, resulted in severe crystal disturbance and emplacement of numerous batholiths.

Parts of the Sweetgrass arch were elevated following Jurassic Morrison deposition and locally most of the Ellis group sediments were removed prior to lower Cretaceous deposition. The lowermost Kootenai formation sandstone was not deposited over the entire Sweetgrass arch area and the Sunburst sand represents the first sediments to cover the entire area (Eardley, 1951, p. 277).

It appears that the Cordilleran geanticline supplied eastward-flowing streams with much debris, as evidenced by the thick clastic sequences of the lower Cretaceous in southeast Idaho, British Columbia and Alberta. These thicknesses indicate some subsidence of the border area, accompanying sedimentation. Present exposures indicate that maximum deposition on the east side of the geanticline

occured along a north-south trough or troughs, extending from southeast Idaho to British Columbia. Volcanic materials in the lower Cretaceous rocks of Alberta and British Columbia show at least local continuance of tectonic activity into Cretaceous time.

The thickness of the Kootenai formation diminishes rather regularly to the east. This would be expected as the distance from the orogenic area increases. Epeirogenic uplift of the border area, Montana, during Jurassic and lower Cretaceous may have been responsible for the withdrawal of the Jurassic sea and the continental environments of Morrison and Kootenai formations deposition.

In the area studied, no angular unconformity appears to exist between the Kootenai formation and the Morrison formation. No angular unconformity was observed between any of the units of the Kootenai formation. There is no evidence of unconformity between Kootenai and Colorado deposition. The abrupt vertical lithologic changes between some of the units of the Kootenai formation may represent local diastems. No evidence of volcanism was found in the area studied.

The basal conglomerate, the thickness of the Kootenai formation, and the clastic nature of the rocks indicate uplift of the source areas. Apparently no orogenic activity affected the area of study during Kootenai deposition. The possible erosional disconformity at the base of the formation may be evidence for epirogenic uplift at this time.

DEPOSITIONAL ENVIRONMENT

Detailed studies of provenance and environment are beyond the scope of this paper although evidence permits some generalizations. The heavy mineral studies, because of their qualitative nature, and because only five samples were studied, yield only limited information.

Source

Grains of the same mineral species within the same sample exhibit varying degrees of rounding. This is true of quartz from the light fraction of the sandstones and also of magnetite and other heavy minerals. Some grains are euhedral while some are well-rounded. Most of the grains are subangular or subrounded. This variation suggests that more than one source is represented.

Phlogopite is present in small amounts in the lower sandstones. According to Merrill (1903, p. 165), Miers (1929, p. 537), and Milner (1940, p. 511) phlogopite is characteristically associated with calcite and dolomite. Gallant (1940. pp. 28-29) lists, from the Kootenai formation, the following heavy mineral suite: tourmaline, zircon, leucoxene, barite, pyrite, and black opaques, magnetite and chromite which he considers indicative of reworked older sediments.

The quartzite pebbles from the basal conglomerate have a sedimentary origin. The basal conglomerate and many of the

sandstones also contain dark and light colored chert pebbles and grains.

The observations set forth in the previous paragraph present the evidence for a sedimentary origin of some of the Kootenai formation constituents. Specific source formations and areas for the material are conjectural. The quartzite pebbles from the basal conglomerate might have come from Pre-Cambrian quartzites or the Pennsylvanian Quadrant quartzite. Both the Devonian Jefferson formation and the Mississippian Madison formation contain light-colored chert, although it is not known whether those formations were breached at the time the Kootenai formation was deposited. The author has not observed any dark chert locally except small pebbles from a thin conglomerate in the Swift formation of the Jurassic Ellis group.

Feldspar occurs in amounts up to 30% in some of the sandstones, particularly in the upper part of the formation. It is highly weathered and cannot be specifically identified. Its presence, however, suggests a primary source as it is difficult for feldspar to survive two depositional cycles. Some of the unidentified dark minerals found in many of the Kootenai sandstones are undoubtedly pyroxene-amphibole, although they have not been specifically identified. It is not known whether or not any of the feldspar is authigenic. The pyroxene-amphibole minerals also suggest a primary source. As local

intrusions are Laramide in age, it is necessary to look elsewhere for the source area. The author believes that the Nevadian orogenic belt to the west provides the most likely source area.

Transportation

Some quartz grains are frosted and some are clear. Frosted grains are typical of wind-transported material, and indicate wind transportation if the quartz is not second cycle. The roundness and size of the conglomerate pebbles as well as the large amounts of clear quartz grains, indicates water transport for much of the material. The rounding of the chert and quartzite pebbles might indicate transportation over a considerable distance.

Deposition and Environment

The Jurassic Nevadian orogeny affected the region west of the present study area and it appears likely that epirogenic uplift was responsible for withdrawal of Jurassic seas from the area. Furthermore, a continental environment is anticipated.

Paleontological evidence shows the non-marine aspect of certain beds in the Kootenai formation. Ostracods are found on Brock Creek in the "gastropod limestone". Fossils have not been identified in this study but Peck (1941,1951) has identified fresh water ostracods and charophytes from the

upper Kootenai formation near Drummond and near Hoover Creek. Calkins and Emmons (1913, p. 30) identified Goniobasis (?) inorebecens Stanton, Viviparus (?) sp., Unio douglassi Stanton and one other species of Unio, all of which are fresh water forms. Cobban (1955, p. 109) mentions fresh water pelecypods, gastropods, plants, dinosaur bones, fish, and turtle bones from the Kootenai formation of northwest Montana.

The lithologic evidence for environment is summarized below.

1. Limestone and clay pebble conglomerates may indicate breaking up of partially consolidated sediments and sufficient movement of these fragments to produce the characteristic rounding of the pebbles. Generally the pebbles are contained in a matrix of the same material.

2. Characteristically the units of the Kootenai formation undergo a change of lithology along strike. The sandstone units, in particular, are lenticular, thickening or thinning along strike. The basal unit frequently changes from conglomerate to sandstone. At Douglas Creek, a conglomerate channel filling is well developed. These lenticular units and channel fillings provide evidence for stream action and shifting channels of the streams during deposition of the Kootenai formation.

3. The presence of apatite, fluorite, and muscovite suggests a fluviatile or other continental environment, according to Milner (1940, pp. 500-514). Forthermore, these minerals

plus hematite indicate early cementation of the sandstones as they are easily altered by percolating meteoric waters.

4. The alternation of sandstones and shales in the Kootenai-Colorado "transition unit" might have resulted from minor transgressions and regressions of the lower Colorado sea with the environment alternating between beach and marine, perhaps a lagoonal-type of deposition.

5. The degree of sorting in the sandstone units varies although generally the sorting is moderately complete. This suggests reworking, most likely by streams or rivers. Some sandstones, however, are poorly sorted and contain large amounts of silt and clay in their matrices. The impurities indicate rapid deposition with little or no reworking of the material.

6. Although limestones are not abundant in the Kootenai formation, several beds are present in addition to the "gastropod limestone". The limestones typically contain much sand, silt, or clay, and are interpreted as having been deposited in a fresh water lake, as suggested by the continental nature of the clastic constituent of the formation. The detrital material present in the limestones is interpreted as representing simultaneous clastic and chemical deposition.

7. The thick shale units of the formation must be considered in a discussion of environment. They could represent

floodplain deposits, but if so, mud cracks or other evidence of a sub-aerial environment should be present. Such features were not observed. It seems more likely that the shale sequences represent material deposited in a fresh water lake, carried a further distance from shore by the transporting current and deposited contemporaneously with siltstone and sandstone being deposited nearer shore and perhaps with limestone being deposited further from shore.

8. The coal seams of the Great Falls area and their associated flora indicate relatively warm and humid climatic conditions. A similar climate probably existed in the area studied. The red and maroon coloration of many units of the Kootenai formation are not necessarily indicative of aridity. Laterites and red soils form at the present time in warm, humid areas. It is not known whether the coloring material was autocthonous or allocthonous.

The thicknesses of the measured sections vary from about 1000 to 2000 feet. No faulting has been found of sufficient magnitude to explain this variation. Local diastems are implied by the abrupt vertical changes of lithology but it is doubtful whether these alone could cause such a variation. Local lakes or basins could allow sediments to accumulate in unequal thicknesses.

The characteristic lithologies of the Kootenai formation are red shales, siltstones, and arkosic sandstones. This sequence of sediments is typical, according to Krynine (1941,

1918-1919) of postorogenic terrestrial piedmont facies and is associated with granitic terraines in areas of youthful topography. The lithologies from the study area contain smaller percentages of the coarser clastics than do the sediments typical of this facies. This suggests that the area of deposition was some distance from the source.

The Nodules

Many of the shales and some of the siltstones, from all five sections, contain scattered and bedded nodules. Locally, these nodules compose 20 or 30% of a unit. All are calcareous, and most are from 1 to 2 inches in diameter, weather a light blue-gray, and are dense and argillaceous although some are finely crystalline. The bedding appears to pass around some, whereas in others, the bedding apparently extends through the nodule. Their shape varies from nearly round to elongate and most are somewhat knobby. In hand specimen, no concentric structure is observed. A single thin section from a typical nodule also fails to reveal any concentricity. Although the nodule is apparently fractured, no regular fracture pattern is observed. The shales which contain the nodules may or may not be calcareous. If a mode of origin can be established for the nodules, additional evidence regarding environment might be obtained.

ECONOMIC SIGNIFICANCE OF THE KOOTENAI FORMATION

The lower Kootenai Sunburst sand is an important oil-producing zone in the Sweetgrass arch. The lowermost sandstone of the Kootenai formation, the Cut Bank sand, contains oil and gas in some areas of the Sweetgrass arch. The First, Second and Third Cat Creek sands produce oil in the Cat Creek field, Petroleum County. Mines near Great Falls, Montana produce or have produced coal from several seams in the Kootenai formation. In central Montana the Kootenai formation is an important aquifer (Perry 1933, plate II, pp. 9, 16, 27, 43, 48). The formation has produced no oil in the area studied although the "gastropod limestone" gives off a petroliferous odor when freshly broken. No coal or artesian water is found in the Kootenai formation of Powell and Granite counties.

SUMMARY

The most significant results of this study are as follows, in order of importance.

1. Lithologic descriptions of five measured sections of the Kootenai formation, are included in the lithologic description section and appendix and are represented in the columnar sections of Plate 1.
2. A twofold subdivision of the Kootenai formation in Powell and Granite counties is proposed instead

of the previous three member division.

3. The author concurs with other writers in designating the "gastropod limestone" as the top of the Kootenai formation.

4. The Kootenai-Colorado "transition unit" is tentatively correlated with the Colorado Blackleaf sandy member of northwest Montana.

Suggestions for Further Study

Further study of the Kootenai formation might well be directed along two lines.

1. Detailed studies of heavy minerals from the sandstones of the area and elsewhere in Montana and Idaho may permit correlation on the basis of associations of heavy minerals. Heavy mineral studies might provide additional information as to the source areas for the Kootenai formation.

2. Further studies of cross-bedding, ripple marks, size and shape of grains, and more detailed fossil collecting may make possible a more complete environmental reconstruction.

APPENDIX

Lithologic Descriptions

The following descriptions are Section B, measured about one-half mile west of Hoover Creek, in Sec. 4, T. 10N., R. 11 W.

Unit	Thick. (ft.)	Cum. Thick. to Top of Unit	Description
49	27	934	Limestone, "gastropod limestone", dense to coarsely crystalline, light gray-brown to dark brownish gray. Percentage of fossils varies considerably from almost none, 925-930 ft., to perhaps 50-60% in some beds. Bedding massive except platy (1/4-2 in.) from 925-930 ft. and 1 ft. thick from 931-934 ft. Unit is a very prominent cliff-former on Hoover Creek. Fossils are mostly gastropods with some pelecypods.
	9.5	907	Covered.
48	6.5	897.5	Limestone, nodular, with thin seams of shale, hard, splintery, dark gray, surrounding some of the nodules which are dense to medium crystalline, medium dark gray, weathering mottled maroon and light gray, average dia. 9-10 in.
47	5.5	891	Siltstone, sandy, slightly shaly, slightly calcareous, in beds 1/2-2 in. thick, medium reddish-maroon, contains scattered 3-4 in. dia. nodules, medium gray, weathering mottled tan and maroon. Composition: silt and clay

			particles 80%, fine sand-size kaolinized feldspar, subangular-subrounded, 10-15%; remainder is cement.
46	10.5	885.5	Shale, silty, fissile, very splintery, non-calcareous, medium reddish-maroon.
	12	875	Covered, shale, maroon, contains many 1-2 in. dia., blue-gray weathering nodules.
45	4	863	Siltstone, slightly calcareous, medium reddish-maroon. Contains 30% of calcareous nodules, 2 in. dia., medium gray, weathering reddish-maroon and light blue-gray.
44	62	859	Shale, and shale, silty; interbedded in 4-5 ft. beds. Shale is soft, fissile, non-or slightly calcareous, bright maroon, containing scattered or bedded, calcareous nodules between 809-810 ft., 818-819 ft., 829-830 ft. Nodules are medium gray, weathering light blueish gray. Silty shale is slightly or non-calcareous, fissile and splintery, dark grayish-maroon, slightly harder and more resistant than the shale.
	13	797	Covered, probably maroon shale or maroon silty shale.
43	3.5	784	Limestone, silty, in beds 6 in. thick, dense to finely crystalline, light brownish-gray.
42	3	780.5	Shale, soft, very fissile, non-calcareous, dark maroonish-purple containing limestone nodules about 1 in. dia., finely crystalline, medium greenish-gray on fresh surface, weathering reddish-maroon.
41	6.5	777.5	Siltstone, calcareous, in beds 1/4-1/2 in. thick, medium red, fresh and weathered. Lower 6 in. is conglomerate; composed

			of 40% limestone pebbles .1 mm -2.5 mm dia., rounded, sub-rounded, gray and brownish gray, weathers to light blue-gray in a maroon matrix of silt and clay, calcareous cement.
40	9	771	Shale, moderately fissile, very calcareous, medium brownish-maroon, contains some 1 in. dia. calcareous nodules of the same color.
39	4.5	762	Limestone, silty, massive, dense, medium greenish-gray, weathers buff, contains some nodules, dark gray and weathering light bluish-gray.
38	4	757.5	Shale, soft, very fissile, non-calcareous, dark bluish-gray, weathers dark maroon.
37	6.5	753.5	Sandstone, fine-grained, very calcareous, massive, low porosity, medium gray, weathering medium gray-brown, brittle. Composition: quartz 75%, dark minerals 10%, carbonate cement and matrix, if any, 15%.
36	3.5	747	Shale, soft, fissile, slightly calcareous, dark maroonish-gray, weathers light grayish blue. Contains some 1 in. dia. calcareous nodules, same color.
35	22.5	743.5	Shale, soft, fissile, very calcareous, bright maroon; with two beds of shale, silty, resembling unit 34 between 730-733, 738-740 ft. Scattered 1-6 in. limestone nodules, argillaceous, maroon-weathering.
34	9.5	721	Shale, soft, fissile, slightly or non-calcareous, maroon; interbedded in beds 1-1.5 ft. thick, with shale, silty, fissile, and splintery, variably calcareous,

			dark maroon. Unit is about 1/3 shale and 2/3 silty shale.
33	3.5	711.5	Shale, soft, fissile, non-calcareous, bright maroon.
32	7.5	708	Limestone, shaly, silty, in beds about 1/4 in., mottled maroon.
31	1.5	700.5	Sandstone, fine-grained, very calcareous, medium gray, weathers lighter brownish-gray. Composition: quartz (frosted and clear) 75-80%, unidentified dark minerals 5%, calcareous cement 15-20%.
30	16	699	Shale, fissile, very calcareous, mottled light and dark reddish-maroon, contains about 10% of limestone nodules 1-4 in. dia. Nodules are both bedded and scattered, dark gray on fresh surface, weathering mottled rusty-brown and light blue-gray. Fractures may be coated with limonite.
29	2.5	683	Siltstone, sandy, very calcareous, mottled gray and maroon, resembles unit 28 except finer grained.
28	1	680.5	Sandstone, medium-grained, very calcareous, massive, medium gray, weathering brownish-gray, hard and brittle, contains 5-10% of small lenses of gray, red-weathering calcareous siltstone. Composition: quartz, light and dark, 80%, calcite cement 20%.
27	3.5	679.5	Siltstone, shaly, calcareous, maroon, weathering maroonish-gray, lower 1 ft; upper 2.5 ft. interbedded limestone, argillaceous, nodular, gray, blue-gray weathering, and sandstone like unit 26 in 3-4 in. beds.
26	1	676	Sandstone, medium-grained, very calcareous, massive, medium gray,

			weathers light brownish-gray, very hard and brittle, not very porous. Composition: quartz 60%, unidentified dark minerals 5-10%, matrix and carbonate cement 30-35%.
25	1.5	675	Siltstone, shaly, very calcareous, dull maroon, weathering lighter brownish-maroon, contains maroon, light blue-gray weathering, argillaceous limestone nodules, about 3 in. dia.
24	2	673.5	Shale, moderately fissile, calcareous, medium brown, weathers light brown, contains a few scattered 1-3 in. calcareous nodules, same color.
23	2	671.5	Limestone, argillaceous, finely crystalline, light gray-green, tan weathering. Lower and upper thirds of this unit are limestone with shale, silty, fissile, strongly calcareous, maroon, interbedded.
22	19	669.5	Shale, very soft, fissile, slightly calcareous lower part becoming more calcareous in the upper part, medium purplish-maroon.
21	6.5	650.5	Limestone, sandy, finely crystalline, in 1-4 in. beds, slabby, medium gray fresh, weathering light brownish-gray, very hard and brittle.
20	12	644	Shale, fissile, strongly calcareous, medium brownish-gray, weathering light reddish-brown, contains some 2-4 in. calcareous nodules same color as the shale.
19	4	632	Shale, slightly silty, fissile, non-calcareous, medium gray-brown, weathering light yellowish brown.

18	105.5	628	Sandstone, medium and fine grained, non-calcareous, platy, in 1/8-1/2 in. beds, medium to light gray brown on fresh surface, weathering brown, bright yellow-brown, or light gray-brown. Chief variation in this unit is the difference in color. Composition: quartz 50-60%, feldspar 10-15%, biotite and phlogopite 5-15%, matrix of silt and clay 15-20%.
17	3	522.5	Shale, soft and fissile, non-calcareous, drab reddish brown.
16	32.5	519.5	Shale, calcareous, locally, soft and fissile, maroon, medium gray-blue, contains many 3-4 in. calcareous nodules, argillaceous, dense, dark gray, weathering buff or blue gray. (Boundaries of units 7-16 are approximate within 1-2 ft.)
15	7.5	487	Siltstone, non-calcareous, medium maroonish gray fresh, weathers brighter maroon.
14	10	479.5	Sandstone, fine-grained, non-calcareous, in beds 1/4-1 in. thick, medium gray fresh surface, weathers brownish gray, friable. Composition: quartz 40%, feldspar 20%, unidentifiable dark grains 15%, clay-silt matrix and cement.
13	8	469.5	Siltstone, non-calcareous, very thin-bedded showing dark maroon and gray laminae 1 mm thick, splits into 1/4 in. plates, overall color is medium grayish-maroon. Unit contains some dark gray, dense, argillaceous, calcareous nodules 2-10 in. dia., weathering reddish-gray.
12	7.5	461.5	Shale, very soft and fissile, non-calcareous, bright maroon, very poorly exposed.

11	8.5	454	Siltstone, sandy, shaly upper 2 ft., non-calcareous, in beds 1/4-1/2 in. thick, medium maroonish-red, fresh and weathered. Composition: sand-sized feldspar 5%, dark mica 5%, silt and clay particles 90%.
10	4	445.5	Sandstone, fine and medium-grained, non-calcareous, massive, porosity probably 10-15%, medium gray-brown on fresh surface, weathers dark red brown. Composition: quartz 30-50%, feldspar 10-15%, unidentified dark minerals 25%; unidentified matrix and cement (ferruginous or siliceous) compose the remainder of the rock. Grains are mainly subrounded.
9	36	441.5	Shale, locally, silty, soft, fissile, slightly or non-calcareous, poorly exposed. Contains some scattered gray, light blue-gray weathering calcareous nodules 2-3 in. dia.
8	12.5	405.5	Siltstone, micaceous, non-calcareous, in beds 1/2-1 in. thick, medium brownish-maroon, weathers grayish-maroon, very hard and resistant.
7	28.5	393	Sandstone, medium and fine-grained, massive, or in beds 2 in. to 1 ft. thick, slightly calcareous, medium gray, moderately porous, grains angular to subrounded, some showing crystal faces. Composition: quartz 70%, feldspar 10%, unidentified dark minerals 10%, fine-grained matrix and cement 10%.
	221	364.5	Covered, thick soil mantle, but probably includes maroon shale, siltstone and light-weathering limestone.
6	8.5	143.5	Siltstone, calcareous, and limestone, silty interbedded; both shaly, light gray fresh and weathered.

5	9.5	135	Conglomerate, grains 1 mm. to pebbles 5-20 mm, may locally grade laterally and vertically into coarse-grained calcareous sandstone; pebbles are subangular to rounded and are aligned with their long axes parallel to the bedding plane. Composition: limestone pebbles, argillaceous, dense to fine crystalline, medium to dark gray, weathering light blue-gray to tan, 50-80%; limestone, buff to orange, dense, argillaceous, 10%. Remainder of conglomerate calcareous cement.
4	22.5	125.5	Limestone, argillaceous, platy, in beds 1/4-2 in., greenish-gray fresh surface, weathers buff or tan, resistant.
	32	103	Covered. Interval includes light gray-blue weathering shale, maroon fissile shale, with light blue-gray weathering calcareous nodules.
3	25.5	71	Sandstone, medium-grained, cross-bedded, beds 1/16-1/4 in. thick, low porosity, gray, weathers to a banded black and tan in the lower 21 ft., and to pinkish gray in the upper 4 ft. Composition: quartz, mostly clear 85%, kaolinized feldspar 5%, dark chert 5%, silica cement about 5%. Grains are mostly subrounded to sub-angular; black bands have a higher chert content and may be cemented by iron in part.
2	13	45.5	Shale, soft, very fissile, non-calcareous, bright red.
	17.5	32.5	Covered.
1	16	16	Sandstone, medium to coarse-grained, quartzitic, cross-bedded, in beds 1/16-1/8 in. thick, contains angular pebbles of siltstone 6-12 mm dia. There pebbles compose up to 10% of some beds, are medium

to light gray. Composition: quartz (frosted and clear) 80-85%, dark chert 5%-10%; silica cement about 5-10%; porosity low. Grains are mostly angular to sub-angular. Contact between Kootenai and Morrison formations is not observed here but unit is presumed to be the base on the basis of float.

The descriptions following are of the Kootenai formation, exposed along Brock Creek, Secs. 3 and 10, T. 10 N., R. 10 W. Units a through g are the Kootenai-Colorado "transition zone" which is quite well-exposed here.

Unit	Thick. (ft.)	Cum. Thick to Top of Unit	Description
			Colorado Shale
g	3.5	163	Sandstone, fine-grained, quartzitic, brown.
f	18	159.5	Shale, black and light yellow-brown and shale, silty, black, calcareous, with 2 thin beds of fine-grained sandstone, quartzitic, fine-grained.
e	4	141.5	Sandstone, quartzitic, fine-grained, dark gray, weathering reddish-gray.
d	9.5	137.5	Covered.
c	19	128	Quartzite, or sandstone, quartzitic, medium-grained, ripple marked.
b	64	109	Shale, silty, black; interbedded with limestone, argillaceous, black.
a	55	55	Covered.
52	26+	1095	Limestone, "gastropod limestone" with some shale beds. Limestone is dense to medium crystalline, mostly black and dark gray in 2 in.-1 ft. beds. Gastropod and pelecypod shells and fragments comprise 0-60% of the limestone.

			The lower 1 ft. is alternating shale, black, and limestone, in 1 in. beds. There is a 3 ft. shale bed from 1087 - 1090 ft. A 6 in. bed containing many ostracods occured at 1090 ft. Shales are fissile, strongly calcareous, black.
51	4	1069	Shale, soft, fissile, very calcareous, light greenish gray, limonite stained.
	8	1065	Covered, by talus from unit 50.
50	71	1057	Sandstone, medium-grained, non-or slightly calcareous, mostly massive but in beds 1/2-1 in. thick, porosity low, light brownish gray. Composition: quartz (frosted, subrounded-subangular) 50-80%, feldspar 5-15%, biotite and phlogopite 2-5%, unidentified dark minerals 10-15%, matrix (clay and silt) and cement average 5-10% or more.
49	7.5	986	Claystone, locally silty, slightly to strongly calcareous, massive, medium gray to light greenish-gray.
48	19.5	978.5	Shale, soft, moderately fissile, silty in upper 4 ft., slightly calcareous, mottled maroon and brown lower 2 in., dull maroon above that.
47	4.5	959	Sandstone, silty, fine-grained, very slightly calcareous in beds 1/4-1 in. thick, friable, medium grayish-brown. Composition: quartz 50%, dark mica 5%, unidentified matrix and carbonate cement, 45%.
46	6	954.5	Shale, soft, fissile, non-calcareous, dark brownish-maroon, containing a few calcareous nodules 2-6 in. dia., light greenish-gray, weathering brownish-red.

45	11	948.5	Claystone, calcareous, massive, light grayish-green. Contains 30 % of coarse grains and granules, rounded mostly, black.
44	16.5	937.5	Shale, soft, variably fissile (almost a claystone in places), non-calcareous, light grayish-green.
43	23	921	Sandstone, quartzitic, medium-grained, non-calcareous lower part, becoming slightly calcareous at the top, in beds 1/4-1 in. thick, lower 10', very hard and brittle, porosity low, massive about this, medium gray. Composition: quartz 80%, unidentified dark grains 10%, fine-grained matrix, and cement (silica and/or carbonate) 10%.
	6.5	898	Covered, bedding slightly disturbed; may possibly be a fault zone but doubt if much displacement.
42	4.5	891.5	Sandstone, fine-grained, argillaceous, non-calcareous, medium greenish-brown. Composition: quartz, feldspar, mica, in silt and clay matrix. Unit is poorly exposed.
41	3.5	887.0	Shale, soft, fissile, non-calcareous, medium reddish-maroon.
40	5.5	883.5	Siltstone, non-calcareous, in 1/2-2 in. beds, bright brownish-maroon, contains 1-2% of mica (muscovite?).
39	14.5	878	Shale, soft, fissile, non-calcareous, medium red-brown, containing a 6 in. bed of siltstone, calcareous, from 870-870.5. Shale contains a 6 in. bed of nodular, argillaceous limestone at 875 ft.; nodules are dense, medium gray, weather buff.

38	4	863.5	Shale, soft, fissile, non-calcareous, medium olive and greenish-brown.
37	2	859.5	Claystone, calcareous, medium greenish-gray, weathers buff. Contains 10-20% of angular to subrounded grains of dark-gray claystone or shale.
36b*	28.5	857.5	Shale, soft, fissile, slightly calcareous, contains some calcareous nodules, 2-3 in. dia., gray, weathering light gray and maroon. The lower 14 ft. is mainly siltstone, shaly, dull dark maroon, harder than the shale, slightly calcareous.
36a	21.5	829	Claystone, shale, sandstone, silty sandstone, grading from claystone at base to silty sandstone at top. All in beds 1/16--1/4 in. thick, all non-calcareous. Below 815' color is greenish-gray and above 815 ft. gray and dull maroon. The fine-grained sandstones contain quartz, feldspar, mica, (phlogopite, muscovite, and biotite) in a matrix of clay and silt particles.
35	52.5	807.5	Siltstone, sandy, non-calcareous, medium gray with small maroon lenses; interbedded in 2-3 ft. beds with shale, and shale, silty; both dull maroon and non-calcareous. The 3 lithologies are present in about equal proportions; some calcareous nodules, scattered, 1-4" dia., gray, weathering light blue-gray and maroon. Shale is fissile and soft. No apparent regular sequence of alternation.

* It is necessary to designate some units by letter (as in the case of 36a, 36b), because of misnumbering of units while in the field.

34	18	755	Siltstone, micaceous (biotite), platy, in 1/16-1/4 in. beds, slightly calcareous, mottled maroon and medium gray.
	36	737	Covered.
33	25	701	Shale, soft, very fissile, slightly or non-calcareous, bright reddish-maroon.
32	7.5	676	Sandstone, medium and fine-grained, slightly calcareous, in 1/8-1/4 in. beds, mottled dark maroon and medium gray. Composition: quartz 40%, feldspar 10-15%, unidentified minerals 10%, unidentifiable matrix and cement (carbonate and/or iron) 35%; interbedded in 1 ft. beds with shale, soft, fissile, non-calcareous, maroon.
31b	39.5	668.5	Siltstone, sandy, non-calcareous, in beds 1/8-1/4 in. thick, dark brownish-maroon.
31a	72	629	Sandstone, medium-grained at base, becoming finer grained at the top, slightly quartzitic, non-calcareous, mostly massive, moderately hard, medium gray-brown. Composition: quartz (subangular-subrounded, frosted and clear). 65%, feldspar (kaolinized) 10%, unidentified dark minerals 10%, matrix of clays and siliceous cement 15%.
	11	557	Covered.
30g	21	546	Sandstone, medium and fine-grained, slightly calcareous, in beds 1/2-1 in. thick, medium gray, composition: quartz 40-50%, feldspar 20-30%, unidentified dark minerals 10%, matrix of silt and clay, 10-20%.
30f	14	525	Covered, shale, silty, maroon.

30e	7.5	511	Shale, soft, fissile, non-calcareous; interbedded with siltstone, sandy, non-calcareous, medium gray-brown.
30d	7	503.5	Sandstone, fine-grained, silty, non-calcareous, in beds about 1/4 in. thick, moderately porous. Composition: quartz 30-50%, biotite and phlogopite 5-10%; silt and clay compose the rest of the rock.
30c	10.5	496.5	Limestone, argillaceous, dense, massive, dark gray, weathering light blue-gray.
30b	25.5	454.5	Claystone, silty, non-calcareous, in 1 ft. beds, greenish gray.
30a	4	397	Shale, silty, non-calcareous, in 1/4 in. beds, light greenish-gray.
29	3	393	Claystone, non-calcareous, in 2-6 in. beds, hard and brittle.
28	29	390	Shale, soft, fissile, calcareous, dark gray, weathering light gray-brown; interbedded 3-12 in. beds of limestone, argillaceous, massive, dense, dark gray, weathering buff, spaced 8 ft. apart.
27	4.5	361	Siltstone, clayey, in beds 1/8-1/4 in. thick, non-calcareous, medium-light gray-brown.
26	5.5	356.5	Limestone, like unit 25.
	23.5	351	Covered, probably limestone, shaly, buff weathering.
25	26.5	327.5	Limestone, dense, argillaceous, in 1-2 ft. beds, dark gray, weathers buff.
24	2.7	301	Claystone, shaly in 4-6 in. beds, non-calcareous or slightly calcareous, mostly in beds 1/4-1 in. thick.

23	11.5	274	Shale, fissile, and claystone, calcareous, in beds 6-12 in. thick, mottled maroon and light gray-green, some calcareous nodules. Shale is more calcareous.
22	8.5	262.5	Claystone, shaly in places, slightly calcareous, light gray-green, contains a 3 in. dia. chert cobble, highly polished, rounded.
21	9.5	254	Claystone, silty, calcareous, maroon, interbedded with shale, fissile, calcareous, mottled maroon and grayish-green.
20	12.5	244.5	Shale, soft and fissile, calcareous, light gray-green; interbedded in 3-6 in. beds with claystone, same color, more calcareous.
	14.5	232	Covered, shale and claystone, blue gray.
19	7	217.5	Claystone, calcareous, in 1 ft. beds, medium gray-blue, weathering lighter blue-gray with much limonite staining. Contains two 3-4 in. beds of shale, fissile, non-calcareous, blue-gray.
18	7.5	210	Shale, variably fissile, non-calcareous, dark blue-gray. Contains two beds of nodules up to 12 in. dia., average 4 in. dia., same color as the shale, slightly calcareous. Two beds occur at 205 ft. and 207 ft.
17	6	202.5	Shale, soft, very fissile, non-calcareous, green, with a 1 ft. bed of claystone, siliceous, massive, light greenish-gray.
	5	196.5	Covered.
16	4.5	191.5	Shale, slightly fissile, non-calcareous, medium grayish-purple;

			interbedded in 6 in. - 1 ft. beds with mudstone, conglomeratic, siliceous, same color, hard, brittle. Mudstone contains about 20-30% of 1-2 mm granules and pebbles, angular to sub-rounded, of gray chert; smoky quartz 5%; remainder is clay and silica cement.
	22.5	187	Covered.
15	3	164.5	Sandstone, quartzitic, fine and medium-grained, massive, non-calcareous, white, weathers mottled light rusty brown and white; grains are frosted, contains occasional rounded-subrounded, black chert pebbles about 1/4 in. average dia, quartz grains 95%, and siliceous cement 5%.
14	22.5	161.5	Shale, soft, fissile, non-calcareous, medium maroon, with a 2 ft. bed of sandstone from 154-156 ft. Sandstone fine-grained, quartzitic, thin bedded, massive weathering, non-calcareous, mottled maroon and light gray, porosity probably 15-20%. Light mottling is almost 100% quartz grains and the darker maroon splotches contain a high percentage of silt. The cement is silica and/or iron oxides.
	6	139	Covered.
13	1.5	133	Sandstone, fine-grained, silty, non-calcareous, massive, low porosity, dark maroon. Composition: quartz 40%, feldspar 10%, matrix of silt and clay with perhaps siliceous cement.
12	7	131.5	Shale, fissile, maroon, calcareous, contains three thin beds of calcareous nodules weathering light grayish-maroon.

11	2	124.5	Sandstone, fine grained, silty, quartzitic, non-calcareous, in 3-6 in. beds, very hard and resistant, medium maroon. Composition: quartz grains 40-60%, silt-clay matrix and silica cement make up the remainder of rock.
10	6	122.5	Siltstone, sandy, non-calcareous, in beds 6 in. thick, contains a few bright red-weathering pebbles of siltstone about 6-12 mm dia., medium to dark grayish-maroon. Composition: quartz 15-20%, silt and clay 75-80%.
9	11	116.5	Sandstone, fine-grained, quartzitic, non-calcareous, in beds 1/4 in. thick, weathers into 6-18 in. blocks, light gray brown, weathering darker red brown, very hard and brittle. Composition: clear and frosted quartz grains 70%, feldspar 20%, unidentified matrix and siliceous cement 10%.
	20	105.5	Covered, sandstone, fine-grained to silty; upper 10 ft. shale, maroon.
8	12.5	85	Sandstone, medium and fine-grained, non-calcareous, cross-bedded, thin-bedded, blocky weathering, gray brown fresh surface, weathers reddish, hard and resistant. Composition: quartz grains, subangular, clear, 90%, unidentified matrix and cement 10%.
7	9	72.5	Siltstone, slightly sandy, micaceous, slightly calcareous, in beds 1/2-1 in. thick, dark dull maroon.
6	15.5	63.5	Sandstone, like unit 5 but somewhat finer-grained, non-calcareous.

5	10.5	48	Sandstone, medium-grained, non-calcareous or slightly calcareous, massive, cross-bedded, blocky weathering, forming much talus, light grayish-brown. Contains a few limestone pebbles of the same type and size as those in unit 4. Composition: quartz grains 80%, dark chert 10-15%, unidentified matrix and siliceous cement 5-10%.
4	4	37.5	Conglomerate, limestone pebble, pebbles are subangular to sub-rounded, 6-8 mm., dense, gray and brownish gray, blue-gray weathering. Composition: lime-stone, pebbles and grains, 40-60%; matrix of quartz grains, sand-size, silt and clay 30-40 %; carbonate cement, 10%. Inter-bedded in lenticular beds 6-18 in. thick with sandstone, medium-grained, calcareous. Composition: quartz and chert grains 60-70%, matrix of silt and clay 20-30%, carbonate cement 10%. Unit is very hard and resistant.
3	19.5	33.5	Sandstone, medium-grained lower part becoming fine-grained at top, quartzitic, in beds 1/2-6 in. thick in lower part, in 1/2-1 in. beds upper part. The lower 4 ft. contains a few scattered light gray-brown pebbles. Composition: quartz 90%, unidentified and siliceous cement 10%.
2	8.5	14	Conglomerate, chert pebble with some 2-3 in. lenses of quartzitic sandstone. Conglomerate occurs in lenses 6 in. to 2 ft. in thickness. Except for lenses, bedding is not apparent. Composition: chert pebbles, 6-12 mm dia., rounded to subangular, light gray and black, 20-60%; matrix

			of quartz-chert grains and granules 30-70%, siliceous cement 10%. Percentage of pebbles decreases toward the top. Color is like unit 1. Upper contact gradational to unit 3.
1	5.5	5.5	Sandstone, medium grained, quartzitic, non-calcareous, cross-bedded, non-porous, very resistant. Lower part contains a few black rounded-subrounded chert pebbles 6-12 mm dia., becoming more numerous in upper part. Pebbles compose about 5% of the total volume of the rock. Composition: quartz, clear and frosted, 60-70%, chert 10-20%, siliceous cement 5%, chert pebbles 5%. Color is light brownish-gray, weathering reddish-gray.

The following descriptions are of the Kootenai formation (Section D) exposed along Warm Springs Creek, Section 19, T. 10 N., R. 9 W. Units a and b are the Kootenai-Colorado "transition zone".

Unit	Thick. (ft.)	Cum. Thick. to Top of Unit	Description
b	60	209	Quartzite, fine and medium-grained, cross-bedded, very hard, white, with rusty staining many places. Composition: clear, angular-subrounded quartz grains 90-95%, unidentified dark grains 1%, siliceous cement 5-10%. This unit greatly resembles the Pennsylvanian Quadrant quartzite of this area.
a	149	149	Covered, by quartzite float and is relatively flat indicating softer beds.
	111	1452	Covered, Top of this interval is the upper float limit of the "gastropod limestone". The limestone here is medium to finely crystalline, has a petroliferous odor when freshly broken, dark gray or black, containing both gastropod and pelecypod fragments and whole shells. The fossil percentage is variable as in other sections. The "gastropod limestone" was not found exposed here.
	88	1341	Covered.
	52	1253	Covered, shale and siltstone, maroon.
	90	1201	Covered.

	93.5	1121	Covered, shale, and siltstone, maroon, as well as sandstone, fine-grained, gray.
15	67.5	1027.5	Sandstone, fine-grained, silty, slightly calcareous, platy, in beds 1/4-1 in. thick, porosity probably 10% or less, medium brown. Composition: quartz 20-30%, feldspar 20-30%, biotite and muscovite 5%, unidentified dark minerals 10%; silt-clay matrix and cement compose the rest of the rock. This lithology is interbedded with shale, silty, micaceous, fissile, non-calcareous, dark dull maroon; about 50% of each type in 6 in.-5 ft. beds.
	50	960	Covered, but interval contains float of sandstone, fine-grained, medium gray; and shale, maroon, fissile, containing blue-gray weathering limestone nodules.
	53	910	Covered.
	467	857	Covered, in the lower 65 ft. float from units 11-14; from 455-627 ft. float of buff weathering limestone; sandstone, medium-grained, gray brown, exposed poorly at 627 ft. From 627-857 ft. is forest cover, maroon shale and siltstone float.
14	25	390	Siltstone, clayey, non-calcareous, very compact, in 1/2-3 in. beds, gray-green.
	14	365	Covered, probably like unit 13 as float is similar.
13	9	351	Limestone, argillaceous, dense, in beds 6 in. to 1 ft. thick, except in 1/4 in. beds upper 2 ft., very hard and resistant, contains some pelecypod shell fragments, some carbonate filling

			of fractures, dark gray, weathering tan.
12	8.5	342	Limestone, argillaceous, dense, black, weathers light blue-gray.
11	29.5	333.5	Limestone, argillaceous, dense, black, weathers light tan, hard and brittle.
	54	304.5	Covered, 250-290 ft. is siltstone and maroon shale; 290-304 ft. is limestone like unit 11.
10	14.5	250.5	Shale, soft, fissile, calcareous, light gray-blue; interbedded with limestone, argillaceous, dense and finely crystalline, gray-green, weathering light blue-gray.
	18	236	Covered.
9	42	218	Sandstone, medium-grained, quartzitic, porosity low, non-calcareous, hard, in beds 1/16-1/8 in. thick, cross-bedded, breaks into 1-3 ft. blocks, light gray, grains are subangular-subrounded, mostly frosted. Composition: quartz 85-90%, dark chert 5%, unidentified matrix and cement 5-10%.
8	20	176	Siltstone, sandy, non-calcareous, in 1/8-2 in. beds, medium brownish-maroon, contains perhaps 20% of fine-grained quartz grains.
	30	156	Covered, shale, maroon, containing calcareous nodules.
7	18	126	Sandstone, medium-grained, quartzitic, massive, non-calcareous, medium gray, weathers dark reddish-gray. Composition: quartz 80-85%, dark chert 5%,

			light gray chert, 3-5%; remainder is siliceous cement.
	28	108	Covered, siltstone, sandy, maroon, and sandstone, fine-grained, gray.
6	2	80	Sandstone, medium-grained, slightly quartzitic, non-calcareous, moderately porous, medium gray-brown, weathering lighter gray-brown, contains several seams of hematite. The grains are clear to frosted, subangular to subrounded. Composition: quartz 80-85%, chert (light and dark) 5%, interstitial limonite 5%, siliceous cement 5%.
5	1.5	78	Sandstone, conglomeratic, medium and fine-grained, massive, strongly calcareous, lenticular, thins to 1 in., 20 ft. along strike, medium brownish-gray, weathering red. Composition: quartz 60%, chert 20%, pebbles 2-8 mm of fine-grained quartzite and light brown limestone, 5%, clay matrix and carbonate cement 15%.
4	7.5	76.5	Sandstone, medium to coarse-grained, slightly quartzitic, massive, grains angular-subangular, medium brownish-gray. Composition: quartz 70%, black chert 10-15%, feldspar 5%, clay matrix and silica cement 5-10%, light gray chert 5%.
	36	69	Covered, includes sandstone, medium grained, quartzitic, light gray; sandstone, fine-grained, with siltstone pebbles.
3	2	33	Sandstone, coarse grained-granular, quartzitic, massive, non-calcareous, medium gray-brown, weathering light reddish-brown, grains mostly angular-subangular. Composition: quartz $\leq$ 50%, black chert $\leq$ 40%, silica cement, and iron, 10%.

	12	31	Covered, sandstone similar to 2.
2	4.5	19	Sandstone, fine-grained, silty, non-calcareous, platy, in beds 1/4-1/2 in. thick, light gray, weathering yellowish brown. Composition: quartz 20-30%, feldspar 20-30%, chert 10%, matrix of clay and silt particles 30 %.
1	14.5	14.5	Sandstone, quartzitic, medium-coarse grained, non-calcareous, conglomeratic in lenses about 1 ft. thick, cross-bedded, beds mostly about 1/16 in. thick, but breaks into 1-1.5 ft. slabs, medium gray fresh and weathered. Grains are mostly clear and are angular to sub-rounded. The conglomeratic lenses contain about 10% of chert pebbles, black and light gray, also 10-15% of chert grains 1/2-1 mm dia. Composition: quartz 70-80%, chert 5-10%, siliceous cement 10-15%.

The following are descriptions of the Kootenai formation section E exposed along an anticline, along Douglas Creek, Secs. 24 and 25, T. 9 N., R 13 W. Units above Unit 43 are the Kootenai-Colorado "transition zone".

Unit	Thick. (ft.)	Cum. Thick. to Top of Unit	Description
			Colorado Shale
a	15	106	Sandstone, fine-grained, calcareous, bedding indistinct, medium greenish-brown, includes quartz and a high percentage of dark minerals, very hard, low porosity.
	19	91	Covered.
b	2	72	Sandstone, medium and fine-grained, calcareous, massive, low porosity, hard, light brownish gray. Composition: quartz 60%, feldspar 10%, unidentified dark minerals 15%, unidentified matrix and carbonate cement 15%.
	70	70	Covered, by "gastropod limestone" float, softer, less resistant beds.
43	10	1204	Limestone, coarse crystalline, in beds 6 in. to 2 ft. thick, contains 50-70% of gastropods, light brownish-gray, weathering buff. This is the last exposure of gastropod limestone. Numerous calcite-filled fractures.
	3	1194	Covered.
42	3	1178	Limestone, like unit 41, except appears more crystalline and is less resistant.
	12	1175	Covered.

41	11	1163	Limestone, medium-coarsely crystalline and/or grained (appears to be composed, at least in part, of detrital grains of carbonate) bedded 2-3 ft., very fetid odor, contains 50-60% of gastropod fossils, some secondary fracture filling by carbonate, light grayish-brown.
40	10	1152	Limestone, argillaceous, finely crystalline, medium greenish-gray, weathering light blue-gray, no apparent fossils in unit.
39	9	1142	Limestone, argillaceous, in beds 1/16-1/4 in. thick, non-fossiliferous, composed apparently of detrital grains of calcite cemented with calcite, light greenish-gray, mostly covered.
38	3	1133	Limestone, argillaceous, dense and finely crystalline, in 1 ft. beds, medium gray-green, weathering buff, containing a few gastropod fossils.
	15	1130	Covered, by float from "gastropod limestone".
37	2	1115	Sandstone, fine-grained, calcareous, fairly porous, in 1/8-1/4 in. beds, light gray, weathering light pinkish-gray. Composition: quartz 60%, feldspar 10%, mica 2-3%, dark minerals 5%, matrix and carbonate cement 20%.
	31	1113	Covered, shale, maroon and gray, contains many limestone nodules 1-2 in. dia.
36	7	1082	Sandstone, fine-grained, silty, calcareous, in beds 1-6 in. thick, low porosity, light gray, weathering medium reddish-brown. Composition: quartz (light and smoky) 75%, unidentified dark minerals 5%, silt-clay matrix and carbonate cement 20%.

35	19	1075	Shale, 1056-1060 ft., soft, fissile, calcareous, dark brown; 1060-1075 ft., siltstone, shaly, calcareous, dull brownish-maroon. Both contain calcareous nodules averaging about 1 in. dia., weathering light blue-gray.
34	28	1056	Sandstone, medium-grained, calcareous, soft and friable, bedded 1/16-1/4 in. cross-bedded, locally more calcareous, weathering into knobs or balls, light gray. Composition: quartz 25%, feldspar 45%, unidentified dark minerals 10%, silt and clay matrix with carbonate cement 20%. Sand becomes slightly conglomeratic at 1033-1034 ft., very conglomeratic, lenticular 1034-1040 ft. Conglomerate is composed of rounded-subrounded 4-40 mm pebbles of buff weathering limestone 30%, light chert 20%; matrix of sand, medium and fine-grained, clay, with carbonate cement 50%. Matrix includes both quartz and feldspar grains.
	30	1028	Covered, shale, maroon, calcareous, containing small, light gray-weathering, calcareous nodules.
33	19	998	Limestone, sandy, fine-grained, in beds 6-12 in. thick, medium gray-brown, weathering medium reddish-brown, contains probably 50% sand and silt.
32	19	979	Shale, silty, soft, calcareous, medium brownish-maroon, contains some 1-2 in. limestone nodules, dense, medium gray, weathering light gray.
31	13	952	Sandstone, medium-grained, calcareous, bedded in 1/4-2 in. beds, porosity low, grains mostly clear, angular-subrounded, light brownish-gray, weathering to darker

			brownish-gray. Composition: quartz 70%, feldspar 5%, unidentified dark grains 10%, carbonate cement 15%.
30	32	939	Sandstone and shale, interbedded; 5 beds sandstone, 2 ft. thick separated by 4 ft. shale beds. Shale, soft, fissile, calcareous, maroon; contains numerous limestone nodules, medium gray, weathering light blue-gray. Sandstone, fine-grained, clayey, calcareous, massive, hard and brittle, low porosity, medium gray, weathering red-brown. Composition: quartz 50%, unidentified dark grains 15%, unidentified matrix and carbonate cement 35%.
29	12	907	Sandstone, medium and fine-grained, in 6-12 in. beds, grains subrounded, color medium gray, weathering dark red brown. Composition: quartz 60%, feldspar 5%, unidentified dark minerals 15%, light chert 2%, fine-grained matrix and carbonate cement 20%.
28	19	895	Shale, soft, fissile, moderately calcareous, reddish maroon, contains some 1-4 in. calcareous nodules, dense, calcareous, gray, weathering light blue-gray.
27	3	876	Sandstone, fine-grained, calcareous, low porosity, in 3-6 in. beds, very hard and brittle. Composition: quartz 70%, unidentified dark minerals 5%, silt-clay matrix and carbonate cement 25%.
26	11	873	Shale, soft, calcareous, bright reddish-maroon, contains numerous 1-2 in. nodules which are calcareous, dense, argillaceous, medium greenish-gray, weathering light blue-gray.

25	7	862	Siltstone, very calcareous, sandy, in beds 1/2-1 in. thick, light gray, weathers to mottled red and gray. The only sand grains identified were quartz. About 20% is sand-sized grains.
24	21	855	Shale, soft, fissile, calcareous, maroon and reddish-purple, poorly exposed.
	21	834	Covered, shale, and/or siltstone, maroon.
23	6	792	Sandstone, medium-grained, calcareous, in beds 1/4-1 in. thick, platy, light brownish gray. Composition: quartz 60%, light chert 5%, dark chert 5%, unidentified matrix and carbonate cement 30%.
22	17	786	Shale, soft, fissile, slightly or non-calcareous, light green and maroon, contains scattered buff and olive weathering calcareous nodules, 1-3 in. dia.
21	4	769	Sandstone, medium and fine-grained, very calcareous, in beds 1/4-1 in. thick, platy, light brownish gray. Composition: quartz 60-70%, unidentified dark minerals 10-15%, fine-grained matrix and carbonate cement 15-30%.
20	15	764	Siltstone, sandy, very calcareous, in beds 1/4-3 in. thick, medium gray, weathering reddish-brown.
	17	749	Covered. Probably like unit 20.
19	29	732	Shale, soft, fissile, calcareous, maroon, lower 4 ft.; upper 25 ft. is shale, silty, calcareous, mottled maroon and green. Upper 5 ft. contains several 1-6 in. beds of sandstone, fine-grained, calcareous, slightly porous,

			medium to dark gray. Composition: quartz 40%, unidentified dark minerals 40%, matrix of clay-silt and carbonate cement 20%.
18	22	703	Shale, soft, strongly calcareous, mottled maroon and light gray-green, contains many 1/2-1 in. dia. nodules, calcareous, weathering light blue-gray.
17	8	681	Siltstone, non-calcareous, in beds 1/4 in. thick, weathers into small blocks, medium-reddish-maroon.
16	7.5	673	Sandstone, arkosic, silty, fine-grained, in beds 1/4 in. thick, slightly calcareous, slightly porous, gray, weathering light reddish, moderately soft and friable. Composition: quartz 20-25%, feldspar 20%, biotite 5%, silt and clay matrix 45-50%.
15	25	665.5	Shale, locally silty, fissile, slightly calcareous, maroon, containing a few red-weathering, gray, 1-3 in. dia. limestone nodules, in beds and scattered, showing bedding continuing through them.
	87.5	640.5	Covered, shale, fissile, calcareous, reddish-maroon, containing a few scattered calcareous nodules which weather light blue-gray.
14	14	553	Sandstone, medium-grained, in 1/4-1/2 in. beds, calcareous, soft and friable, very porous, light gray. Composition: quartz 60%, feldspar 10%, clay matrix and carbonate cement 10%.
13	12.5	539	Shale, soft, fissile, slightly calcareous, maroon, with a 6 in. bed of sandstone from 529-529.5 ft., like those in unit 12.

12	16.5	526.5	Sandstone, 510-513 ft., fine-grained, silty, very calcareous, in beds 1/8-1/4 in. thick, platy, light gray. Composition: quartz, 50%, feldspar 15%, unidentified dark minerals 10%, silt-clay matrix and carbonate cement 25%. Shale, from 513-516 ft., soft, fissile, calcareous, maroon, overlain by 10.5 ft. sandstone like that from 510-513 ft.
11	35	510	Shale and siltstone, shaly; interbedded in 3-5 ft. beds, slightly to strongly calcareous, shale very fissile. Both are medium grayish-maroon. Shale contains several beds of nodules, calcareous, with bedding observably continuing through the nodules. Nodules are mostly 1-6 in. dia., averaging about 2 in., medium red-brown; some have small areas of crystalline calcite within them.
	86	473	Covered.
10	60	387	Claystone, very calcareous, in beds 6 in. to 2 ft., dark brownish-gray to dark gray, weathering light buff or light blue-gray.
	13.5	327	Covered.
9	9.5	313.5	Shale, splintery, variably calcareous, mostly light gray-green and maroon mottled; locally contains 10-25% of rounded pebbles and grains of dark and light gray-green chert.
8	9	304	Limestone, argillaceous, shaly in places, dense, light greenish-gray, weathering buff.
	23	295	Covered, shale, maroon, containing scattered blue-gray-weathering nodules.

7	32.5	272	Sandstone, medium and fine-grained, slightly quartzitic, non-calcareous, quite porous, cross-bedded, weathers in 1-2 in. slabs, light gray, weathering reddish-gray, grains clear and frosted, mostly sub-angular. Composition: quartz 60%, light chert 15%, dark chert 15%, siliceous cement 5-10%.
	92	239.5	Covered. Most of interval is probably maroon shale, and/or siltstone, maroon as the soil is reddish maroon and some small blue-gray weathering nodules are scattered on the surface. Nodules apparently occur exclusively with shale or siltstone.
6	32	147.5	Sandstone, fine-grained, quartzitic, bedded 1-2 in., breaks into 1-2 in. slabs, very hard, non-calcareous, low porosity, pinkish white lower 20 ft., medium-light gray upper 12 ft. Composition: quartz 85-95%, dark minerals 0-5%, silica cement 5-10%.
	30	115.5	Covered. Soil is maroon and a depression is formed across the unit so probably is a shale and/or siltstone interval.
5	5	85.5	Sandstone, medium-grained, slightly quartzitic, non-calcareous, thin-bedded, cross-bedded, red and gray banded, grains mostly clear, sub-angular. Composition: quartz 60-70%, chert (light and dark) 15%, feldspar 5%; cement and matrix compose rest of rock. Cement is both silica and hematite; silica in the lighter bands and silica-hematite in the darker bands.
	5	80.5	Covered, Soil is red so is either a continuation of unit 4 or a more silty interval.

4	3.5	75.5	Sandstone, silty, fine-grained, non-calcareous, very porous, medium brownish-red, breaks into 1 in. blocks. Composition: quartz and feldspar 70%, unidentified including silt and clay matrix and iron oxide cement 30%.
3	10.5	72	Sandstone, medium-grained, quite porous, non-calcareous, in beds 2-6 in. thick, cross-bedded, light brownish-gray, weathering to reddish-gray. Grains frosted and clear, angular to rounded. Composition: quartz 70%, chert 10%, feldspar 10%, unidentified matrix and silica cement 10%.
2	31	61.5	Sandstone, medium to coarse-grained, slightly quartzitic, non-calcareous, in beds 1/8-1/2 in. thick, cross-bedded, weathers in slabs 1-3 in. thick. Contains several beds and "nodules" up to 4 in. dia. of hematite which stains the surrounding rock for several inches. The predominant color is light brown. Pitting has resulted because of lesser resistance to erosion in the iron-rich areas; grains are mostly frosted, subangular to rounded. Composition: quartz 40-50%, chert (dark and light) 40%, clay matrix and cement (silica and/or hematite) 10-15%. In the iron-rich areas the composition appears to be nearly the same except possibly a greater percentage of ferruginous cement. The sandstone is locally conglomeratic, containing 5-10% of sub-angular to rounded chert pebbles.
1	30.5	30.5	Covered, although interval is covered, scattered chert pebbles indicate the basal conglomerate of the Kootenai is present. The base of the Kootenai is, however,

represented north of Gird Creek, by a chert pebble conglomerate, with matrix of silt and clay, and a lower pebble count than in Sections A or C. This interval also includes a sandstone, (sample 1), conglomeratic, coarse grained-granular, non-calcareous, low porosity, grains mostly sub-rounded. Composition: quartz 40%, light chert 20%, dark chert 35%, pebbles (2-8 mm) of chert and sandstone, fine-grained, light brown, rounded-subrounded, 5%, matrix and cement 10%. Sandstone was found as highly weathered float only.

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